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THE LINEAR HOT-WIRE ANEMOMETER AND ITS APPLICATIONS IN TECHNICAL PHYSICS.*

BY

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In the spring and summer of 1912 the writer commenced a series of experiments [1] on the laws of cooling of electrically-heated wires in a stream of air with a view to applying this principle to the accurate measurement of air-velocity.[2] As there is always a great advantage to be gained by being able to plan apparatus, take observations, and discuss experimental results in conformity with a mathematical investigation of the subject, the theoretical problem of calculating the rate of loss of heat from a cylinder immersed

* Communicated by the Author.

[1] An account of these experiments was read before the Royal Society of Canada, May 28, 1913. A full account of the subject, the development of which is briefly sketched in the present article, will be found in a series of papers by the writer: (i) King, L. V., "On the Convection of Heat from Small Cylinders in a Stream of Fluid: Determination of the Convection Constants of Small Platinum Wires, with Applications to Hot-wire Anemometry," *Phil. Trans. Roy. Soc. London*, vol. 214 A, 1914, pp. 373–432; abstract in the *Proc. Roy. Soc. London*, vol. 90A, 1914, pp. 563–570. (ii) *Phil. Mag.*, vol. 29, April, 1915, pp. 556–577. (iii) *British Patent Specification*, No. 18,563, 1914.

[2] It is interesting to note that researches with this idea in view were undertaken almost simultaneously by investigators in England, Italy, Germany, the United States and Canada. Preliminary experiments on the use

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in a stream of fluid flowing at right angles to the length of the cylinder was first discussed in some detail. In the form derived by Poisson and Ostrogradsky the general differential equations for the conduction of heat in a moving medium are intractable. In the particular problem under consideration, the cylinder is supposed to be immersed in a perfect, thermally-conducting fluid, so that the flow around it gives rise to a system of hydrodynamical stream-lines and equipotentials which intersect everywhere at right angles and define a system of orthogonal coördinates. It was discovered by Boussinesq,[3] in 1905, that by referring the conduction of heat to this system of curves instead of to a system of (x, y) coördinates, the equation of heat-conduction when thus transformed is much simplified and takes a form whose solution is comparatively simple. Further progress to a final result requires some assumption to be made as to the conditions of heat-flow at the boundary of the heated cylinder and the fluid flowing past it. On this subject we have, unfortunately, almost no direct physical evidence: Boussinesq assumes, for the purpose of calculation, that the fluid which *slips* past the cylinder is at the separating boundary

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of a platinum wire heated by an electric current for the measurement of wind-velocity were carried out by G. A. Shakespear, at Birmingham, as early as 1902, but were discontinued for lack of facilities in the erection of a suitable whirling table for the calibration of the wires. Electrical anemometry was independently suggested by A. E. Kennelly in 1909 (A. E. Kennelly, C. A. Wright, and J. S. Van Blyevelt, *Trans. A. I. E. E.*, **28**, pp. 363–397, June, 1909), and, although the actual application to anemometry appears to have been made as early as 1911, the results have only recently been published (A. E. Kennelly and H. S. Sanborn, *Proc. of the American Phil. Soc.*, **8**, pp. 55–77, April 24, 1914). Electrical anemometry was also developed independently by U. Bordoni (paper read before the Societé Italiana per il Progresso delle Scienze, October 18, 1911; published in the *Nuovo Cimento*, series 6, vol. iii, pp. 241–283, April, 1912; see also *Electrician*, 70, p. 278, November 22, 1912), and by J. T. Morris (paper read at the British Association, Dundee, September 27, 1912; published in the *Engineer*, September 27, 1912; the *Electrician*, October 4, 1912, p. 1056, and November 22, 1912, p. 278), *British Patent Specification*, No. 25,923, 1913. A form of integrating hot-wire anemometer has also been described by H. Gerdien (*Ber. der deutschen phys. Ges.*, heft 20, 1913). The use of a hot-wire anemometer in the measurement of non-turbulent air currents is described by C. Retschy in a series of short papers published in *Der Motorwagen*, vol. 15, March–July, 1912.

[3] Boussinesq, *Comptes Rendus*, vol. 133, p. 257; also *Journal de Mathématiques*, vol. i, pp. 285–332, 1905.

at the same temperature as that of the surface of the solid; he then neglects an entire term of the differential equation representing the conduction of heat away from the cylinder in the case where the velocity of the stream is zero, and finally obtained for the rate of loss of heat H from unit length of cylinder of radius a immersed in a fluid of small thermal conductivity κ, density σ, and specific heat s per unit mass the formula

$$H = 8\sqrt{(s\sigma\kappa Va/\pi)}\theta_0 \quad \ldots\ldots (1)$$

where θ_0 is the excess of temperature of the cylinder above that of the fluid at a distance. This is known as Boussinesq's Formula and is quoted in several recent papers on the convection of heat.

It was found that the formula (1) did not agree with the results of experiment in the heat loss from small wires: the writer, therefore, undertook the rigorous solution of the differential equations of heat-flow from a cylinder in a stream of fluid in such a way that any boundary condition might be employed at will. Unfortunately, our knowledge of the physical conditions determining the transfer of heat across the boundary separating a solid from a liquid or a gas are still very imperfect. The result in best agreement with observation on heat losses in air was obtained from the assumption of a boundary-condition of constant flux; that is, that the rate of transfer of heat from the solid to the gas is constant over the boundary and independent of the velocity of slip past the solid.

In these conditions, the heat loss per unit length from a cylinder of radius a is given by the equation

$$4\pi s\sigma Va/[\int_0^{4a} e^u K_0(u)\,du] \quad \ldots\ldots (2)$$

where $K_0(u)$ is that solution of Bessel's equation most conveniently defined by the definite integral

$$K_0(u) = \int_0^\infty e^{-u\cosh\phi}\,d\phi \quad \ldots\ldots (3)$$

In order to test the theory, it is necessary to tabulate the function $\int_0^x e^u K_0(u)\mathrm{d}u$. Use is made of the tabulated values of the function $K_0(x)$, and the integral is evaluated step by step by making use of Euler's formula for quadratures, the arithmetical operations being easily carried out by means of a calculating machine. The graph of the function $y = x/[\int_0^x e^u K_0(u)\mathrm{d}u]$ plotted

against $\frac{1}{2}x$ is shown in Fig. 1. Over the range of values of the variable corresponding to the interpretation of the experiments on the convection of heat the curve lies extremely close to its asymptote

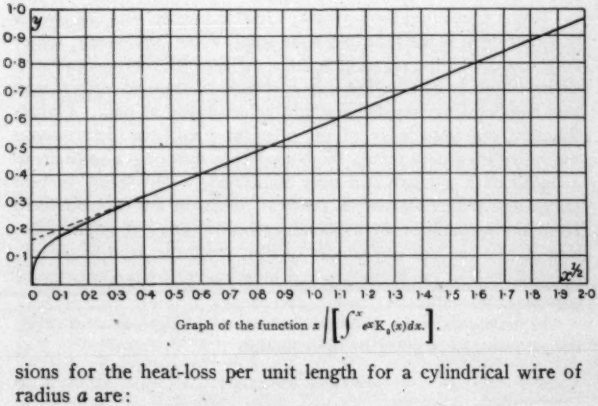
$$y = 1/(2\pi) + \frac{1}{2}[x/(2\pi)] \quad \ldots\ldots(4)$$

while for small values of the variable it can easily be shown that an approximate value is given by

$$y = 1/[(1 - \gamma) - \log \tfrac{1}{2}x] \quad \ldots\ldots(5)$$

γ being Euler's constant, $\gamma = 0.5771$. The corresponding expres-

FIG. 1.



Graph of the function $x \Big/ \left[\int^{x} e^{x} K_0(x)\,dx\right]$.

sions for the heat-loss per unit length for a cylindrical wire of radius a are:

(High velocities) $H = \kappa\theta_0 + 2\sqrt{(\pi\kappa s\sigma a)}\,V^{\frac{1}{2}}\theta_0 \quad \ldots\ldots(6)$

(Low velocities) $H = 2\pi\kappa\theta_0/(\log b/a) \quad \ldots\ldots(7)$

where b in (7) is given by $b = \kappa e^{1-\gamma}/(s\sigma V)$.

The boundary condition of constant flux gives rise to a discontinuity of temperature over the boundary. From the point of view of the kinetic theory of gases, temperature conditions can not be strictly defined in the immediate neighborhood of the heated cylinder, and it is only at a distance of several free paths, when equi-partition of molecular energies is nearly complete, that temperature can strictly be defined and that normal thermal conduction takes place.

It may be argued that the application of the preceding theory to reality is somewhat remote in view of the fact that viscosity has not been taken into account in the preceding analysis. There are many difficulties in the more complete treatment of the problem: not only do the equations for heat-flow become very much more complicated when viscosity is included in the hydrodynamic equations, but it must be remembered that such solutions for stream-line flow as have been obtained for flow of velocity V past a circular cylinder of radius a apply only to values of the fraction Va/ν small compared to unity, ν being the kinematic coefficient of viscosity. ($\nu = \mu\sigma$ where μ is the coefficient of viscosity and σ the density of the fluid: for water at 0° C., $\nu = .0178$ and for air $\nu = .132$). This condition fails to hold over almost the entire range of velocities met with in practice, even in dealing with wires as fine as 1 mil (1/1000 inch) in diameter. It may also be pointed out that nothing is known as to conditions under which stream-line motion gives place to turbulent flow in the case of cylinders as small as the wires employed by the writer in hot-wire anemometry (1 to 6 mils in diameter). In the experiments described below on the determination of convection constants of small platinum wires the writer fully expected to find points of discontinuous behavior on increasing the velocity of the air past the wire; in all these experiments the curves were quite smooth to velocities as high as 30 metres/second. It is thus probable that in the case of these very small cylinders the motion is stream-line throughout, and at the comparatively high velocities employed it is not impossible that the distribution of stream-lines may not differ very much from that in a perfect fluid except in a region in the immediate neighborhood of the cylinder. In these circumstances it is probable that the effect of viscosity is chiefly felt in this comparatively thin "skin," and that the experimental boundary condition of constant flux is an effect of thermal conduction in the "transition layer" under the conditions mentioned.

This point of view receives some support from a powerful treatment of the problem by Lord Rayleigh, based on the principle of similitude.[4] By an application of the theory of dimen-

[4] Rayleigh, "The Principle of Similitude," *Nature*, 95, March 18, 1915, pp. 66–68. The notation is slightly changed to conform to that employed in the present paper. For a further discussion see Riabouchinsky, D., *Nature*, 95, July 29, 1915, p. 591. Also Larmor, *Nature*, 95, August 12, 1915, p. 644.

sions described in his paper it is shown that, taking into account viscosity, the expression for the heat-loss H per unit length should take the form

$$H = \kappa\theta_0 F(aVc/\kappa, c\nu/\kappa) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

the notation employed being the same as in (1), except that c in the present case refers to the specific heat of the fluid per unit volume. F is an arbitrary function of the two variables aVc/κ and $c/\nu\kappa$. In the paper just quoted Lord Rayleigh comes to the following conclusions: "The latter of these ($c\nu/\kappa$), being the ratio of the two diffusivities (for momentum and for temperature), is of no dimensions: it appears to be constant for a given kind of gas, and to vary only moderately from one gas to another. If we may assume the accuracy and universality of this law, $c\nu/\kappa$ is a merely numerical constant, the same for all gases, and may be omitted, so that H reduces to the forms already given[5] when viscosity is neglected altogether, F being again a function of a single variable aVc/κ. . . ."

A little consideration will show that the more general formula (2), and the approximate expressions (6) and (7) obtained by the writer, may, from this point of view, be included as a particular case of the general functional expression (8). From the physical point of view it is evident that little can be done towards the final solution of the problem until further *experimental* evidence comes to hand regarding the precise boundary conditions which exist at the interface of highly-heated metals and gases both at rest and in relative motion.

THE DETERMINATION OF THE CONVECTION CONSTANTS OF SMALL PLATINUM WIRES.

The experimental investigation briefly reviewed in the following pages was undertaken with two purposes in view:

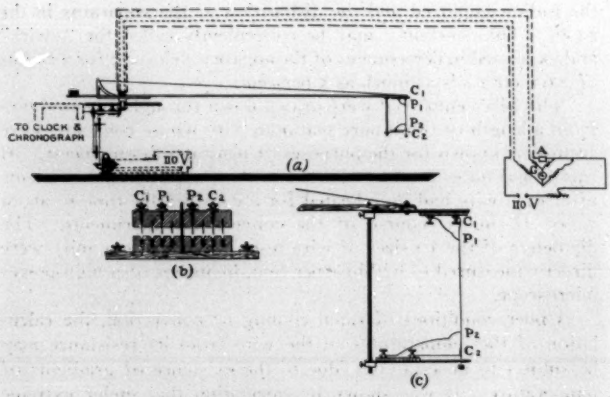
1. To study the laws of the convection of heat from small platinum wires heated by an electric current over as wide as possible a range of temperature, air-velocity, and diameter in the light of the theoretical development outlined above, and to obtain in absolute measure the convection constants of small platinum wires.

[5] Referring to formulæ of the Boussinesq type obtained for the convection of heat from bodies of various shapes immersed in a stream of fluid.

2. To make use of the constants thus obtained in the design of accurate and portable wind-measuring apparatus to form the basis of a standard system of anemometry, as well as to serve for use in a great variety of engineering and aërotechnical problems.

The general arrangement of apparatus necessary to carry out the requisite measurements of heat-losses from a series of platinum wires of diameters 1 to 6 mils is shown in Fig. 2, and con-

FIG. 2.



Rotating arm and diagrams of connections employed in the determination of the convection constants of small platinum wires.

sisted of a rotating arm capable of adjustment to any speed as calculated from a chronograph record. At various lengths along this arm could be clamped a light fork (Fig. 2 *c*) designed to hold the specimens of wire under test. The latter formed part of a Kelvin double bridge, electrical connection being obtained through a central mercury connecting switch (Fig. 2 *b*) and overhead wires to the remainder of the bridge. By means of a rheostat it was possible at each speed to adjust a measured current through the wire so as to bring its resistance to a value corresponding to a predetermined temperature. In this way it was possible to vary at will the various factors of temperature, air-velocity, and heat-loss.

In order to obtain a correct measurement of velocity by the use of a rotating arm, it was found necessary to make a correction for the velocity of the vortex set up in the laboratory. This was accomplished by making use of one of the wires previously tested on the rotating arm as a hot-wire anemometer for measuring the velocity of the vortex set up by the whirling table. For a wire fixed at any radius it was found that the velocity V relative to the air of the room is connected with the velocity V_r relative to the room itself by the relation $V=(1-s)V_r$, s being a constant for the radius employed and the disposition of the apparatus in the room. The constant s may be conveniently called the "swirl" and expressed in percentages of the apparent velocity: for a radius of 2.6 metres s is as much as 5 per cent.

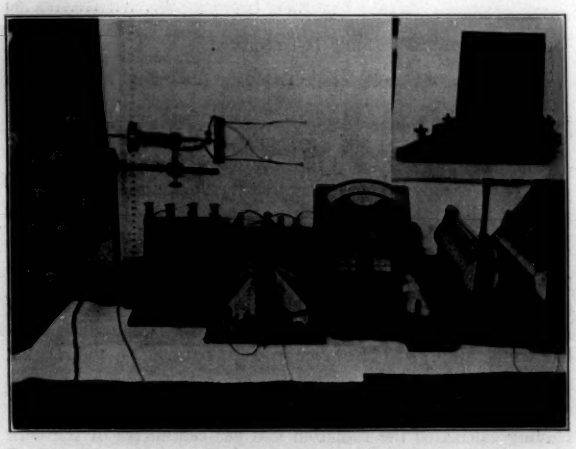
The wires employed were drawn down through diamond dies from a length of 6-mil pure platinum wire whose constants were accurately known for the purposes of platinum thermometry. It was found necessary to redetermine the temperature coefficients after each wire had been heated for a considerable time to about 1200° C. in the course of the convection experiments. The diameters of the 10 sizes of wire tested (from 6 to 1 mil) were directly measured to within 1 per cent. by means of a high-power microscope.

Under conditions of rapid cooling by convection, the calculation of the temperatures of the wire from its resistance may be subject to uncertainties, due to the existence of gradients of temperature. It was shown by calculation that under extreme conditions the excess of temperature of the centre of the wire over that of the boundary can not exceed 0.6° C. at 1000° C., so that this source of error is negligible. More serious is the cooling effect of the leads and potential terminals, which must be so arranged that this source of error may be within the limits of experimental errors. The effect was calculated out in detail and a numerical table was drawn up showing that with the disposition of apparatus of the convection measurements the error due to the leads and potential terminals could be neglected. The possibility of error becomes more serious in the design of hot-wire anemometers with short wires, and in any particular case may be kept within small limits by a reference to the above-mentioned table. The importance of keeping the anemometer wire from

vibration was shown by a mathematical investigation of the error involved.

Observations on the heat-loss per unit length from a series of ten platinum wires of diameters 6 to 1 mil under varying conditions of temperature and wind-velocity were analyzed in detail. For each velocity (corrected for "swirl") the currents required to heat the wire to a predetermined series of resistances (from which the temperatures were calculated) were measured. The

PLATE I.



Portable hot-wire anemometer. The insert in the upper right-hand corner is a photographic reproduction of the mercury connecting switch shown in Fig. 2 *b*.

corresponding heat-loss W in watts per unit length was calculated for each temperature: theory suggested that the results be examined in the light of the formula $W = B\sqrt{V} + C$, where B and C are functions of the temperature and of the dimensions of the wire. When W was plotted against $\sqrt{V}$ for each temperature, a family of straight lines was obtained, and by determining the line of closest fit to the observed points the constants B and C could be found for each wire.

It was found by plotting B against $\theta - \theta_0$, the excess of tem-

perature of the wire above the surrounding air, that the resulting graph approximated very closely to a straight line for a range of temperature attaining to as high as 1200° C.: this result could be expressed by the relation $B=\beta(\theta-\theta_0)$ where β showed the existence of a small temperature coefficient represented by $\beta=\beta_0[1+b(\theta-\theta_0)]$, b having the value $b=0.00008$. Finally, theory required that β_0 be proportional to $\sqrt{a_0}$, a_0 being the radius of the wire. A graph of β_0^2 against a_0 showed this condition to be satisfied, leading to the final result

$$\beta_0/\sqrt{a_0} = 1.432 \times 10^{-3} \text{ (experimental)} \quad (9)$$

The theoretical formula (6) required

$$\beta_0/\sqrt{a_0} = 2\sqrt{(\pi s_0 \sigma_0 \kappa_0)} = 1.66 \times 10^{-3} \text{ (theoretical)} \quad (10)$$

taking $\sigma_0=0.001293$, $\kappa_0=5.66\times10^{-5}$ calorie, and $s_0=0.171$ calorie. The agreement of (9) and (10) must be considered fair in view of the uncertainty attached to the value of the thermal conductivity for air, and also in the fact that the theoretical investigation does not take into account the variation of this and other factors with the temperature gradient in the neighborhood of the wire.

In order to interpret the constant C in terms of formula (6), it was necessary to calculate the contribution of radiation to the term C. It was shown, from the observations of Lummer and Kurlbaum,[6] that the radiation loss from polished platinum at absolute temperature θ° C. is given in watts per cm.² by the relation

$$e = 0.514(\theta/1000)^{4.2} \quad (11)$$

Having calculated the radiation loss per centimetre of the wire from the formula $E=2\pi ae$, the true convection loss $C_0=C-E$ was obtained: it was found for each wire that C_0 was very nearly proportional to the temperature difference $\theta-\theta_0$, and could be represented by the formula $C_0=\gamma_0(\theta-\theta_0)[1+c(\theta-\theta_0)]$, γ_0 being nearly independent of the diameter of the wire and having the value

$$\gamma_0 = 2.50 \times 10^{-4}(1+70a) \text{ (experimental)} \quad (12)$$

[6] More recently the accurate determination of the emissivity of pure platinum has been made the subject of a special research at the Washington Bureau of Standards: Foote, P. D., Bulletin No. 243, vol. 11, January, 1915, pp. 607–612.

According to the theoretical equation (6), $C_0 = K_0(\theta - \theta_0)$, giving

$$\gamma_0 = \kappa_0 = 2.37 \times 10^{-4} \text{ watts (theoretical)} \quad (13)$$

in tolerable agreement with the observed value (12). The coefficient c has the value $c = 0.00114$, which may be considered to represent in large measure the variation of the heat conductivity with the temperature.

It was found that the constant β_0 varied in a marked manner with the inclination of the wire to the direction of the stream, an effect which can be utilized in practical anemometry in determining the direction of the resultant flow in a complicated distribution of air-velocity.

Formula (7) for small velocities agrees in form with the empirical formula proposed by Langmuir [7] to represent the results of his experiments on the free convection of heat from small platinum wires. The corresponding mathematical problem has not yet been solved completely, but may be dealt with in the light of the present investigation by supposing that the wire is cooled by a current of effective velocity V due to the ascent of heated air over the surface of the cylinder. Making use of the constants obtained from the present experiments on forced convection, Langmuir's observations can be interpreted and the velocity of the "effective" convection current estimated: these results are of some importance in hot-wire anemometry, as the "effective" velocity sets a lower limit to the value of the air-velocities which it is possible to measure accurately by this means.

THE LINEAR HOT-WIRE ANEMOMETER.

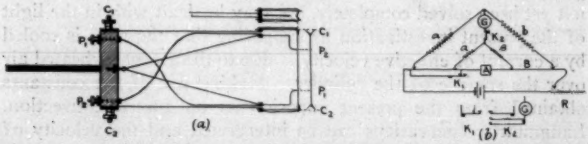
It is interesting to notice that, whereas the requirements of modern science have led to the development of means of measuring a large number of physical quantities to a high degree of accuracy, instruments for the measurement of fluid velocity have, up to within a few years, been extremely imperfect. Confining ourselves, for the moment, to the measurement of air-velocity, the first demand for a means of estimating wind-velocity arose from the needs of meteorology: it is interesting to note, in this connection, that misgivings as to the correctness of absolute

[7] Langmuir, "Conduction and Convection of Heat in Gases," *Physical Review*, vol. 34, p. 415 (1912).

determination of velocities by the well-known Robinson cup-anemometer made themselves felt many years ago, with the result that experiments carried out by Stokes[8] in 1881 and Dines[9] in 1889 led to a marked change in the constant of the instrument.

In recent years the rapid development of aëronautics and the establishment of organized aërotechnical laboratories have led to an insistent demand for an accurate and reliable means of measuring air-velocity to an accuracy of a fraction of one per cent. This need has been met by the development of the pitot-tube employed in conjunction with extremely sensitive pressure manometers. As these instruments are now extremely well known, it is unnecessary to do more than refer to the publications of any of the principal aërotechnical laboratories where specifications of the most satisfactory types of wind-measuring instruments of this kind are given in detail.[10]

FIG. 3.



Details of hot-wire anemometer and connections. (*a*) Anemometer fork. (*b*) Kelvin bridge connections.

While sufficiently accurate under most conditions, the pitot-tube suffers from grave disabilities which prohibit its use in certain circumstances where an accurate measurement of air-velocity would lead to highly interesting results. In the first place, owing to the necessity of measuring small pressure-differences and the use of a sensitive manometer controlled by gravity, the pitot-tube is not easily portable; in addition, the pressure-difference is, for velocities ordinarily met with, so small as to make it extremely difficult, if not impossible, to affect a relay

[8] Stokes, Sir. G., *Proc. Roy. Soc.*, 1881, p. 170. For the early history of the subject see Stokes, "Memoir and Scientific Correspondence," edited by Sir J. Larmor, Cambridge, 1907, pp. 230–240 and pp. 244–252.

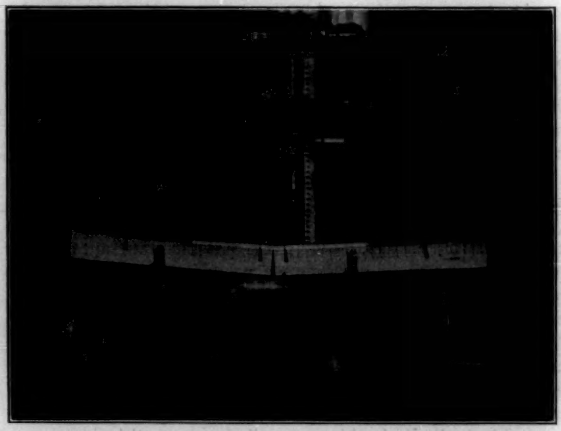
[9] Dines, *Journ. Roy. Meteorological Society*, vol. 15, p. 1.

[10] Note in particular a paper by Rowse, W. C., "Pitot Tubes for Gas Measurement." *Journ. of the Am. Soc. of Mechanical Engineers*, 1913.

capable of operating a recording mechanism. Finally, the pitot-tube is not suitable for measuring variations of velocity close to surfaces or obstacles where the velocity-gradient is extremely high, owing to the comparatively large size of the pitot-tube orifice and the distortion of flow which it would cause under the conditions mentioned.

On the other hand, the use of anemometers based on the hot-wire principle has many advantages in dealing with special prob-

PLATE II.



Linear hot-wire anemometer showing micrometer mounting. The lower part of the figure shows a Töpler manometer for measuring minute pressure differences.

lems to be discussed in greater detail in the sequel. Several forms of instruments of this type have already been developed to a practical form.[11] The special type of instrument developed by the writer with a view to studying the complex problems relating to the stability of the flow of gases in channels and the phenomena of skin-resistance may be called a "linear anemometer" in contradistinction to several forms of integrating instruments already mentioned.

[11] See footnotes (1) and (2).

The special feature of the writer's instrument which has many advantages is the use, in conjunction with platinum anemometer wires, of the Kelvin Double Bridge shown in Fig. 3 *b;* the ratio-coils are adjusted so that $a/b = \alpha/\beta$, in which case a fundamental property of this arrangement is that when a balance is obtained on the galvanometer, $A/B = a/b = \alpha/\beta$ independently of all connecting- or contact-resistances. The resistances A and B refer respectively to the resistance of the anemometer-wire between potential terminals permanently fused to the wire and to that of a manganin resistance. The resistances a and b were made equal and about 500 ohms, while α and β were adjusted to equality at about 250 ohms. In order to protect the anemometer-wire from accidentally burning out, a key K_1 was inserted by means of which it was always short-circuited except when observations were actually being taken; a double-contact key K_2 was inserted in the galvanometer circuit in such a way that contact was first made through a high resistance in the preliminary adjustments; it was also found convenient to connect the galvanometer through an adjustable shunt. The resistance B was constructed of No. 23 B. and S. gauge manganin wire wound non-inductively on an asbestos frame so as to dissipate a maximum amount of heat; its resistance as measured between potential terminals soldered to the wire was adjusted to about four times that of the anemometer-wire at room temperature. By means of a fine-adjustment rheostat R, the current in the anemometer-wire can be adjusted until a balance is obtained in the galvanometer. It is advisable that the rheostat be always readjusted to the position of minimum current to avoid overheating the wire should the velocity of air-flow suddenly diminish; this may easily be accomplished by means of a spring control. In taking a measurement of velocity the key K_1 is pressed down and the current as read by the ammeter slowly increased until on pressing down the key K_2 a balance is obtained on the galvanometer. From the reading of the current i the velocity V may readily be obtained from a calibration curve corresponding to the formula

$$i^2 = i_0^2 + k\sqrt{V} \qquad (14)$$

or from a conversion-table connecting i and V calculated from the above expression.

The ammeter employed by the writer was a Weston direct-current instrument of range 2 ampères; the scale was equally

graduated over this range, each division representing 0.02 ampère; by estimation the current could be read to 0.002 ampère. If the conditions of air-flow are sufficiently steady and it is required to resolve small velocity differences, the use of a Weston Laboratory Standard ammeter is recommended; the scale covers a range of 1.5 ampère and is uniformly graduated directly to 0.01 ampère; by means of a diagonal scale it is possible to subdivide each division directly into fifths, and by estimation into twentieths, so that it is possible to read the current to 0.0005 ampère.

The galvanometer employed was a Weston portable instrument with jewel-bearings, of resistance 277 ohms and capable of detecting a current of about 10^{-6} ampère; this degree of sensitivity is, in fact, ten times more than is necessary. When employed in connection with hot-wire anemometry the constants of damping are very important in determining the rapidity with which observations can be made. It was found that equally sensitive galvanometers varied within wide limits in this respect.

A convenient form of fork suitable for holding in position the anemometer-wires, and offering a minimum of disturbance to the flow of air in its neighborhood, is illustrated in Fig 3 *a*. Fastened to a block of ebonite are the two arms of the fork, consisting of steel strips about 5 mm. in width. At the end of each is soldered a small brass block drilled to receive two fine needles fastened about 1 cm. apart. Threaded through the eyes is a 3-mil platinum wire having its extremities firmly clamped in the brass block just mentioned. The ends of the anemometer-wire are threaded through these two loops and secured in position by being twisted a couple of turns around the wire; the fundamental property of the Kelvin double bridge already referred to only requires the electric contact at these points to be moderately good. The tension in the wire is adjusted by a fine silk thread carried down from each of the brass blocks to an adjustable screw in the centre of the ebonite block; this thread is also effective in preventing lateral vibrations of the fork. Carried up from each end of the ebonite block are two thin steel strips crossing each other to the opposite ends of the fork, insulated from each other and also from the fork by means of thin mica strips. These steel strips, which are held in position along the arms of the fork by two lashings of fine waxed silk cord, serve to brace the fork and at the same time serve as potential leads; at each end is soldered a small brass block drilled to hold a fine needle, at the extremity

of which is soldered a short length of 6-mil platinum wire. To these are soldered one extremity of the 1-mil platinum potential terminals, the other being *fused* to the anemometer-wire; this is most easily accomplished by connecting the wire to the bridge connections and adjusting the current until it is at a bright red heat; the potential wires are then brought to the required position and wound twice around the anemometer-wire; by applying a slight tension while this is being done, a satisfactory fused contact will be effected. The free end should then be broken or cut off close to the anemometer-wire, so as to diminish the cooling effect of the potential leads. The heating to which the wire is subjected during this operation serves to anneal it sufficiently well for permanent use.

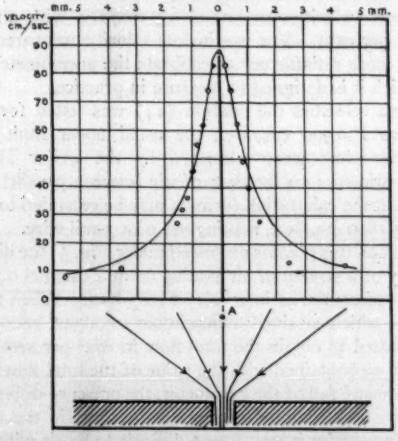
The linear hot-wire anemometer in the form just described has been extensively employed by the writer in a series of researches on the distribution of velocity in the flow of air between parallel planes, and considerable experience has been gained as to the most efficient method of using the instrument. In a paper already referred to[12] the writer has set out in some detail data as to the resolving power, upper and lower limits of correct velocity registration, life of wires, various sources of error, etc., which may be of use to experimenters wishing to employ the linear anemometer in aërotechnical investigations. For detailed directions as to the selection and calibration of anemometer-wires reference should be made to the writer's paper[12] already mentioned.

Although it is possible to determine the constants of formula (14) from the dimensions of the wire and its electrical resistance constants, making use of the absolute determinations described in the first part of this paper, it is preferable to calibrate the wires directly by mounting the anemometer fork on some form of rotating arm, as that shown in Fig. 2 *a*, making the necessary correction for "swirl." Wires were usually calibrated over the range $V = 60$ to 800 cm./sec., enabling the constants of formula (14) to be determined. The relation expressed in this formula between the velocity and the current necessary to maintain the wire at a predetermined temperature (and therefore resistance) has been tested experimentally for velocities as low as 17 cm./sec., and was found

[12] King, L. V., "On the Precision Measurement of Air Velocity by Means of the Linear Hot-wire Anemometer," *Phil. Mag.*, vol. 29, April, 1915.

to hold good within the limits of experimental error. Theoretically the linear relation mentioned is the asymptote to a transcendental curve expressing the true relation between heat-loss and velocity; it is shown, however, that to an accuracy of 2½ per cent. a linear

FIG. 4.



Test of anemometer readings at low velocities: 3-mil wire No. 7.

A short rectangular channel of width 0.75 mm., having a plate at right angles to its length fitted flush with its upper extremity, was set up in the manner illustrated in the lower part of the figure. By means of suitable connections to a gasometer, air from the room was drawn into this channel under a constant pressure-difference of 2.35 cm. water. The distribution of flow at a sufficient distance from the opening of the channel is approximately that which would be set up in a perfect fluid by a distribution of sinks along a line coinciding with the opening of the channel into the plane mentioned. In the neighborhood of a plane bisecting this slit at right angles, where the velocity is measured by the portion of the anemometer-wire between potential terminals, the distribution of velocity is approximately radial. Taking a set of axes (x, y) having as their plane the diametral plane just mentioned, with origin at the centre of the slit, and measuring the axis of y along the direction of the channel, the velocity at any point (x, y) is approximately given by $V = V_0 \sqrt{y^3/(y^3+x^3)}$, V_0 being the maximum velocity at $x=0$. The anemometer-wire, represented by A in the figure, was set by means of a micrometer-screw in various positions in the plane $y=3$ mm.; the observed velocity distribution thus obtained was compared with the theoretical by choosing V_0 to agree with the experimental value at $x=0$. The figure shows that the readings of velocity are fairly accurate for velocities as low as 12 cm./sec.; the deviations are possibly due to the limitations of the simple formula employed in calculating the theoretical velocity distribution.

formula of the type (14) may theoretically be employed when the velocity is as low as that given by the relation $Vd = 1.87 \times 10^{-2}$, V being expressed in cm./sec. and the diameter d in cm. For a 2½-mil wire this limiting velocity is as low as $V = 2.9$ cm./sec.,

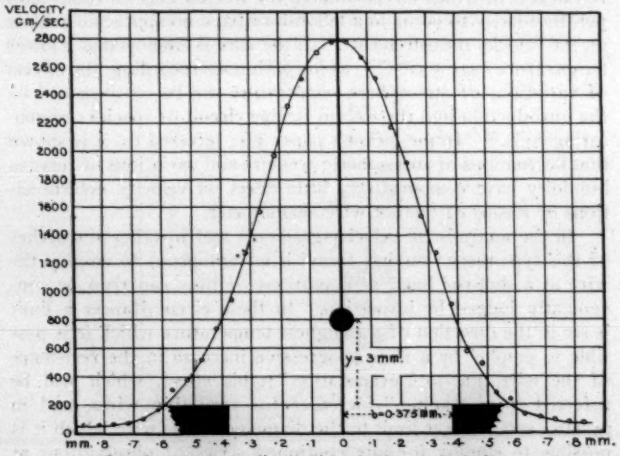
probably much lower than the lower limit imposed by the disturbing effect of the free convection current. Some information on this point can be derived from the experiment described under Fig. 4, in which the distribution of the flow of air into a slit in a plane is measured and compared with that calculated from theory. The evidence there discussed points to the fact that the anemometer registers velocities as low as 15 cm./sec. with an accuracy of a few per cent. For use in low-velocity measurement it is, however, more satisfactory to calibrate the anemometer over the range which it is designed to measure in practice.

At high velocities the relation (14) was tested for velocities as high as $V=900$ cm./sec., the usual upper limit at which anemometer-wires were calibrated by the writer in practice. From experiments on the flow of air between parallel planes, it appears that the calibration formula may be extended to velocities as high as 2800 cm./sec., making use of a 3-mil wire. An example of a test on this point is discussed under Fig. 5: the distribution of velocity of a stream of air issuing from a channel 0.75 mm. in width was measured at intervals of 0.05 mm. When the resulting curve, which attained a maximum of about 2800 cm./sec., was integrated to obtain the total flow in cm.^{3} per second, a fair agreement was obtained with the value of the total flow measured from the rate of fall of the gasometer, the pressure-difference over the length of the channel remaining the same in the two cases. Above this velocity it was found difficult to work with wires of the usual length of about 5 cm., as transverse vibrations are liable to be set up which invalidate the readings and tend to break off the potential leads, while the tension on the wire required to destroy synchronization with the free period of a stretched wire in an air-current is near the breaking-point of the wire. The upper limit of velocity measurement might be increased almost indefinitely by shortening the wire or by using stouter wire; this step results, however, in diminished sensitivity and resolving power, while in the use of stouter wire the working currents increase rapidly and the apparatus has to be specially designed to meet the resulting heating effects.

If the change of velocity just detectable by the instrument is denoted by δV, the ratio $V/\delta V$ which defines the *resolving power* of the anemometer is expressed in terms of that of the ammeter employed in connection with the apparatus; it is shown, in the

writer's paper on precision anemometry,[12] that with an ammeter reading to 0.002 ampère the resolving power of a 2½-mil wire at $V = 800$ cm./sec. is about 140, and the change of velocity just detectable is about 6 cm./sec.

FIG. 5.



Test of anemometer readings at high velocities: 3-mil wire No. 7.

The distribution of velocity illustrated in Fig. 4 was measured by setting the anemometer-wire in various positions by means of a micrometer-screw in a plane at a distance $y = 3$ mm. from the upper extremity of the channel described under Fig. 3. The dimensions of the channel were: width, $2b = 0.75$ mm.; breadth, $d = 5.08$ cm.; length, $l = 5.06$ cm. Integrating this velocity-distribution between the limits $x = +0.92$ mm., the total flow per unit breadth of channel is 182 cm.²/sec. under a pressure-difference of 11.5 cm. water. From a series of observations on the rate of fall of the gasometer for various pressure-differences, the total flow for breadth d was obtained, and hence the flow per unit breadth, assuming approximately uniform distribution of conditions over the breadth. From the curve connecting this flow with the pressure, the value per unit breadth corresponding to a pressure-difference of 11.5 cm. water came out to be 196 cm.²/sec., in fair agreement with the value obtained from the anemometer measurements; the latter is probably an underestimate, owing to the destruction of momentum of flow as the jet travels through the stagnant air in this region. The low velocities beyond the edges of the channel are due partly to a "diffusion" of the jet owing to its dragging action on the quiescent air through which it is flowing, and at a greater distance to an indraught of air from the surroundings into the moving air of the jet. The distribution of velocity over the channel approximates fairly well to a parabola.

Among the sources of error which have to be guarded against in hot-wire anemometry, the most important are those arising from variations of atmospheric conditions. When the anemometer-wire is heated until its resistance attains a predetermined value the temperature reaches an absolutely fixed value, while

the heat-loss depends chiefly on the difference between the temperature of the wire and that of the surrounding air. As a result, fluctuations of atmospheric temperature will affect the calibration constants: in some applications it is of advantage to employ the wire at a high temperature (about 1000° C., or at a red heat), in which circumstances the fluctuations of room temperature likely to occur in a laboratory have no appreciable effect on the velocity measurements. If the wire is employed at a lower temperature (say 500° C.), as in continuous recording, the effects of variations of atmosphere temperature can be compensated by the introduction into the Kelvin Bridge circuit of special compensating coils.[13] In the writer's paper just referred to, it is shown that fluctuations of atmospheric pressure and variations of relative humidity have comparatively little effect on velocity determinations by means of the hot-wire anemometer.

In the analysis of velocity-gradients and in other researches of this type the writer has found it advantageous to employ the wire at a dull-red heat, as conditions of flow can then be conveniently judged by inspection. In these circumstances a limit is set in the direction of the highest temperature which it is possible to employ by a slow progressive increase in the resistance of the wire due to "evaporation"; this effect, which will be referred to as "aging," increases for very thin wires, and in practice sets a lower limit to the diameter of the wire which it is possible to employ for any continued series of observations at about 2½ mils. Experience has shown that in the case of a wire of this diameter the "aging" becomes distinctly noticeable after the wire has been employed to measure about 1000 velocities. In precision measurements of velocity it is advisable to recalibrate the wire at intervals of about 500 observations; when possible, the wire should be employed at a much lower temperature, in which case the difficulties due to "aging" are negligible.

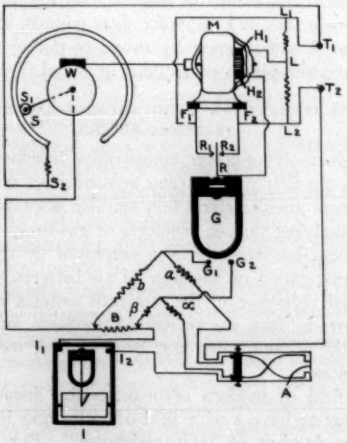
As many technical applications of the hot-wire anemometer require continuous observations of air-velocity to be made, there is no difficulty in designing a means of obtaining a continuous record easily interpretable in terms of wind-velocity.[14] In Fig. 6

[13] For details see the writer's paper (footnote 12), pp. 571–573.

[14] King, L. V., "Improved Means for Determining the Rate of Flow of Fluids," *British Patent Specification*, No. 18,568, 1914.

is shown one of the several possible arrangements whereby the resistance S of the adjustable rheostat may be automatically adjusted so that the galvanometer G is always balanced, while the current i through the anemometer-wire is registered, on a recording ammeter I, giving a record easily interpretable in terms of wind-velocity. The moving contact of the rheostat, S_1, is attached to an arm which can be caused to rotate in either direction by means of a worm-gear W connected to the shaft of a

FIG. 6.



Design for recording hot-wire anemometer.

small direct-current motor M, whose field F_1F_2 is permanently connected across the line terminals T_1T_2. Across the terminals T_1T_2 are inserted in series two equal high resistances L_1L and LL_2: one of the brushes is connected to L and the other to the movable pointer R of a sensitive galvanometer-relay G; the terminals L_1 and L_2 are connected to the contacts R_1 and R_2. The remainder of the apparatus corresponds to the connections shown in Fig. 3 *b*, the galvanometer G being replaced by a galvanometer-relay and the ammeter by a recording instrument. The mode of operation of the recording anemometer can be easily followed

from Fig. 6: when the anemometer-wire undergoes a change of temperature, and therefore of resistance, due to a change of wind-velocity, the galvanometer is thrown out of balance and contact is made with one or other of the terminals R_1 or R_2; current is allowed to pass through the armature of the motor M in one or the other direction, thus causing a corresponding rotation of the shaft and worm. The direction of rotation is so arranged that the resistance S_1S_2 is altered in such a way that the movable contact R of the relay-galvanometer is brought back to the position of no contact. It is estimated that the total weight of the recording anemometer can be kept under sixty pounds, so that a design of this type should be specially suited to taking records of air velocity from aëroplanes or airships in actual flight.

VARIOUS APPLICATIONS OF THE HOT-WIRE ANEMOMETER TO TECHNICAL PHYSICS.

The high resolving power, comparative freedom from serious corrections, together with extreme sensitiveness at low velocities, make the linear anemometer a very suitable laboratory instrument for use in studying various problems of gas-flow. In particular, the instrument has recently been employed by the writer in a detailed investigation on the flow of air between parallel planes with especial reference to the study of criteria of stability of laminar flow; in fact, the system of precision anemometry described in the present paper was evolved with special reference to this problem.

In the field of modern aëronautics the linear anemometer would appear to have a wide field of usefulness in the study of the inner mechanism of "skin resistance." For instance, it is easily seen, from the preceding account of the instrument and of its actual performance, that it would be a comparatively easy matter to study the gradients of velocity in the neighborhood of thin planes held lengthwise in a uniform stream of air, or near the walls of a large-dimensioned channel, such as a wind-tunnel, to within a small fraction of a millimetre from the surface. As the phenomenon of skin-resistance, which is associated with the establishment of turbulence, takes its origin in the region close to the rigid boundary, it would seem that valuable information on "eddy-motion" under such conditions might be obtained by this means.

It is only necessary to turn over the pages of any of the recent reports of the aërotechnical societies of various countries to notice numerous tests in which the use of the hot-wire anemometer might be made to yield valuable information. For instance, in the "Technical Report of the Advisory Committee for Aëronautics,"[15] 1912–13, Jones and Paterson give a detailed investigation of the distribution of pressure over the entire surface of an aërofoil; a measurement of velocity-distributions taken in the same circumstances would prove of considerable interest in the interpretation of the results. In the study of complex problems relating to the design of aëroplane propeller blades and the fans of rotary blowers there should be no serious difficulty in mounting a calibrated anemometer-wire on the blades and making electrical connections through slip-rings to the Kelvin bridge, which lends itself specially well for the purpose.

From the point of view of the aviator, a knowledge of the structure of the wind is of great importance. Initiated by Langley many years ago, this branch of knowledge is now being made the subject of continuous observation.[16] In this connection the investigation of gusts and their connection with large-scale eddies is a branch of meteorology for which the hot-wire anemometer would seem especially applicable, as by employing a thin wire the lag to variations in velocity is extremely small. In this connection there should be no difficulty in developing a special form of recording anemometer based on the principle of the oscillograph for reading even minute variations of wind-velocity. Eddy-motion in the atmosphere has recently been made the subject of an interesting theoretical contribution by G. I. Taylor[17] which promises to have important developments and applications.

In many branches of engineering the problem of heat trans-

[15] "Technical Report of the Advisory Committee for Aëronautics," 1912–13: London, Darling and Son, 1914. A valuable survey of the field of aërodynamics has recently been given by Hunsaker J. C., "A Review of Hydrodynamical Theory as Applied to Experimental Aërodynamics," paper presented at the meeting of the International Engineering Congress, San Francisco, Cal., September 20–25, 1915.

[16] See "Report on Wind Structure," by J. S. Dines: "Technical Reports of the Advisory Committee for Aëronautics," 1908–09 to 1912–13.

[17] Taylor, G. I., "Eddy-motion in the Atmosphere," *Phil. Trans. Roy. Soc. London*, vol. 215 A, 1915, pp. 1–26.

mission is an important one and one whose laws have not as yet been accurately formulated. In particular, the design of electrical machinery and equipment requires the evaluation of heat losses by free convection to be made with as much accuracy as possible.[18] In the investigation of the laws of free convection in simple cases the linear hot-wire anemometer as developed by the writer would seem capable of being employed with advantage. By employing an extremely small measuring current and a sensitive galvanometer, the hot-wire anemometer may also be employed as a resistance thermometer capable of measuring temperature to 0.1° C., or, with special precautions, to 0.01° C. In this way it would be possible to explore both temperature and air-velocity in the immediate neighborhood of surfaces being cooled by free convection. As regards more specific problems, the linear anemometer would seem capable of being easily adapted to exploring the distribution of air-currents in electric generators; *e.g.*, an anemometer-wire could be employed to analyze the velocity-gradients in the air-gap between the armature and pole-pieces of a generator and connect these with heat-losses measured in the usual way.

Another important branch of engineering requiring as accurate a knowledge as possible of the laws of heat convection is the designing of modern internal combustion engines, both as regards cooling by water circulation and by forced-air draught.[19]

From the theoretical point of view, considerable progress has recently been made by Taylor[17] in formulating the mechanism of heat-transfer from a surface into a fluid under conditions of eddy-motion. The final experimental verification of the formulæ there developed will require numerous experiments to be carried out on heat-losses under these conditions. In this field the linear anemometer would seem capable of being employed with advantage in the measurement of both velocity and temperature gradients. An important point in this connection is its property of giving a consistent measure of turbulent velocity,[20] under which

[18] A detailed review of this aspect of the subject is given by Langmuir, "Laws of Heat Transmission in Electrical Machinery," *Trans. A. I. E. E.*, 32, 1913, pp. 301–323.

[19] Note in this connection interesting papers by Lanchester, F. W., and Stanton, T. E., "Surface Cooling and Skin Friction," Report of the Advisory Committee for Aëronautics, 1912–13, pp. 40–47.

[20] King, L. V., *Phil. Trans. Roy. Soc.*, 214 A, 1914, p. 407.

conditions the use of a pitot-tube is difficult to use and uncertain in its readings.

Closely allied to problems of heat convection are those of evaporation or diffusion of vapors from liquid surfaces. From the theoretical point of view the mathematical statements of the two problems are practically identical, so that the theoretical formulæ which have been found to apply to calculations of heat-losses will probably be found to apply to evaporation problems as well. In practice it is obvious that rate of evaporation from a liquid will depend very largely on the conditions of air-velocity in the immediate vicinity of the surface. In investigations on these subjects the linear anemometer would seem capable of giving valuable information on velocity gradients and their connection with rates of evaporation. The subject is one of considerable practical importance, and has recently been studied in some detail by meteorologists.[21]

McGILL UNIVERSITY,
December 11, 1915.

A New Glass and an Application of the Low Reflectivity of Glass for Radiant Heat. E. C. SULLIVAN and W. C. TAYLOR. (*The Journal of Industrial and Engineering Chemistry*, vol. 7, No. 12, December, 1915.)—A glass has recently been developed at the Corning Glass Works, Corning, N. Y., which is unique among borosilicate glasses in that it combines very low thermal expansion with resistance to attack by reagents. It is of simple chemical composition, being free from heavy metals and metals of the magnesium-calcium-zinc group. Its characteristic properties are due, in part, to very high silica content, which incidentally has necessitated special technic for its melting and working. Its specific gravity is 2.25, and mean linear expansion coefficient (19°–350°), 0.0000032.

Culinary ware made of the glass was found to bake food more rapidly than earthenware or metal. The reason for this lay, in the case of the metal, in the greater reflectivity of the metal for radiant energy. Experiments showed that its resistance to fracture from a blow is greater than that of enamelled earthenware or ordinary crockery.

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[21] For a detailed bibliography of the subject see papers by Livingston, Mrs. Grace J., *Monthly Weather Review*, 1908, pp. 184, 301, 375; 1909, pp. 68, 103, 157, 193, 248.

Uses of Platinum. J. M. HILL. (*Mineral Resources of the United States, Calendar Year, 1914—Part I,* United States Geological Survey, 1915.)—One of the most important uses of platinum is as a catalyzer in what is technically known as "contact mass" in the manufacture of fuming sulphuric acid and sulphur trioxide. There are several kinds of "contact mass," the two most used in this country being on asbestos or magnesium sulphate bases. The mass is made by soaking the base in solutions containing platinum chloride and afterwards heating it. This treatment results in a more or less complete distribution of very fine particles of metallic platinum throughout the mass. Some "contact mass" contains as much as 7 or 8 per cent. by weight of platinum, and other manufacturers make a mass containing as little as 0.2 per cent. metallic platinum by weight.

It is impossible at this time to state the quantity of platinum used in the sulphuric acid industry in this country, but it is believed that the loss of platinum in well-regulated practice is very small. The platinum does not enter into the chemical reaction, but rather acts as an exciter in the formation of sulphur trioxide, which, on combination with water, yields sulphuric acid.

Platinum dishes and utensils of many kinds are still a necessity in chemical laboratories and in many chemical industries, but the uses of the metal in the electrical industry are each year becoming fewer. In the manufacture of incandescent lamps a large quantity of platinum was formerly used, but at present wires made of nickel-chromium alloys or metallic tungsten or metallic molybdenum are used. The resistance wires of electric furnaces and heaters at one time contained considerable platinum, but metallic molybdenum has now to a considerable extent replaced the more expensive metal. Formerly the electric ignition points of gas engines were made of platinum, but it is believed that most of the spark-plug points now used are made of metallic tungsten.

The dental industry once used a large quantity of platinum in making artificial teeth. It is understood that recently metallic molybdenum plated with platinum is widely used rather than pure platinum. The art of platinum plating has now been perfected to so remarkable a degree that jewellers are no longer under the necessity of using so much platinum as formerly in making jewelry, though platinum is still considered the best setting for precious gems. This use of platinum, however, is somewhat subject to the reigning fashion. Of interest in this connection is a bill which was prepared by the National Jewelers' Board of Trade of New York, early in 1914, for presentation to the New York Legislature, making it a misdemeanor to mark inferior jewelry "platinum" unless it is 0.950 fine or contains 95 per cent. platinum group of metals. A somewhat similar law was passed by the Swiss Federal Council, to be effective March 1, 1914. This law provides that "Upon request of the manufacturer, seller, or purchaser, articles having a minimum platinum content of 95 per cent. will receive the official stamp of the Alpine goat."

THE DEVELOPMENT OF A DYNAMIC THEORY OF SOIL FERTILITY.*

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INTRODUCTION.

EXCEPTING only the healing art, there is probably no branch of human inquiry which has received more attention than the relation of crop production to soil factors, or, as it is more popularly styled, "soil fertility." Again, excepting only medicine, there is no subject about which there are as many and firmly held popular misconceptions. And with the same exception, probably, there is none about and of which there have been so many and such bitter controversies and polemics. It is inevitable that a comparison between the progress of medicine and agriculture should come to mind, for these twin arts were through the ages the incentive to the development of what we are pleased nowadays to call pure science. The science of chemistry in a very real way has always been regarded as the handmaiden of the sister arts of medicine and agriculture from the time of the early alchemists until to-day, when a share of her service is demanded also by the younger sister, manufacture or industrial arts. Many of the past controversies of chemistry have been controversies over agricultural theories, and a very large share of the epoch-marking items in the progress of chemistry has come from consideration of agricultural problems. The histories of chemistry and of agriculture are inseparably intertwined, as are those of chemistry and medicine. It is to be regretted that the development of the art of agriculture has lagged behind that of medicine. But progress there has been; the light of promise is shining brighter than ever before; and

* Presented at a joint meeting of the Section of Physics and Chemistry and the Philadelphia Section of the American Chemical Society held Thursday, October 28, 1915.

it is the purpose of this lecture to show the gradual development of scientific views, based on a large body of established facts, to a point where it is manifest that the time is in sight when agriculture will have passed from the avocation of the peasant to the profession of a learned man, and that, to be successful, the farmer of the future will have to possess the same type of training, education, and equipment that is now recognized as necessary for the physician, lawyer, or engineer. The time has arrived when our universities should recognize the *desirability* of providing proper equipment in faculty personnel and laboratory facilities for advanced work or "research" in crop, plant, and soil problems; and the time is probably near when they will be forced to acknowledge the *necessity* of doing so.

To carry out the purpose of this lecture it will not be necessary, nor will it be desirable, to attempt a complete presentation of the various individual views that have appeared from time to time. Fortunately, the early literature has been summarized in readable and entertaining accounts, as by Shenstone in his "Life and Work of Justus von Liebig" (The Century Science Series), and, more recently, by the accomplished director of the Rothamstead Experimental Station, Dr. Russell, in "Soil Conditions and Plant Growth" (Monographs on Biochemistry). The later literature is easily accessible, and the last few years have seen the production of numerous texts in which it is summarized.

It will be practicable here to sketch only an outline of the steps in a progression from the early crude deductions based on slim and often faulty evidences, through the masterly generalizations made possible by an improving scientific technic, to the present advanced stage of a large and orderly body of knowledge, bristling with suggestions for further inquiries, and supported by the technical equipment of the most highly developed of the physical sciences.

EARLY THEORIES.

While farming has always attracted a few people, gardening has always had its charms for the many. Hence it is natural that the problems of seed germination, growth of plant, and kindred subjects should have attracted the attention of thoughtful men in all times, and references could be found in the liter-

ature of all known times. The agricultural literature of later Roman times had reached considerable proportions. But, from the modern viewpoint, the first important work on the theory of plant production is that of van Helmont (1577–1644), who carried out a planned experiment, growing a willow shoot in a vessel filled with soil and so protected that nothing, so far as he knew, was added to the soil but water. In five years the willow had increased in weight from 5 pounds to upwards of 169 pounds, while the soil mass of some 200 pounds had decreased but a few ounces. Influenced by the philosophical views of his time, van Helmont thought he had found the explanation of plant growth, and that water was the "principle" of fertility. Many years later Priestley (1775), noting that air vitiated by animals was apparently made pure by growing plants, tested the problem experimentally with mint plants. But his compeer, Scheele, insisted that growing plants, like animals, vitiated the atmosphere, and not even the discovery of oxygen, made independently by Priestley, as well as by Lavoisier, gave the true explanation until the work of Ingen-Housz (1779) and Senebier (1782) showed that plants absorb carbon dioxide only in the light and that oxygen absorption takes place in the dark. The modern conceptions of the function of chlorophyll came, of course, much later. There has been in this line of inquiry a steady progression of knowledge and theory, with the final acceptance of a dynamic viewpoint.

But meanwhile the functions of the soil were not entirely ignored. Glauber (1656), shortly after van Helmont's classical research, gave a logical and at the same time an apparently sufficient demonstration that saltpetre was the "principle" of fertility. Later, Mayow (1674) found that the saltpetre content of the soil fluctuated from season to season, and explained his observations by the hypothesis that the nitre of the soil is "sucked out" by growing plants. These investigations were, logically, forerunners of the later observations of Boussingault (1838), who advanced arguments and experimental evidence for the fixation of atmospheric nitrogen by growing plants, and of the still later work of Liebig, Warrington, Lawes, Hellriegel and Wilfarth, Widnogradsky, and a host of brilliant modern investigators which has developed into the fascinating field of soil bacteriology and nitrogen fixation by living organisms. And, from

the nature of the case, the phenomena of living organisms are dynamic in character.

Again going back, we find Boerhaave (1727) to be the first, apparently, to recognize the importance of the soil solution as the nutrient medium for plant growth. But Boerhaave's views were by no means as influential as those put forward by Jethro Tull (1730), who, recognizing root pressure as great and of obvious importance, considered it a provision of nature to force the finer soil particles into the "lacteal mouths" of the roots where these particles became the "proper pabulum" for the plants. Tull's very real contributions to husbandry in the way of inventions of tillage machines and observations on tillage methods, together with a vigorous literary style, good observational powers, and forceful deductions, gave him a widespread and great authority.

Following Tull's time, the development of analytical chemistry led to the recognition that mineral substances were of value or necessity to growing plants. It was frequently observed from the earliest time that minerals, added to the soil, increased plant growth. Finally came the work of Senebier and de Saussure, Boussingault, and Liebig, not to mention numerous lesser lights, confirming the importance of mineral nutrients, introducing the rapidly developing technic of analytical chemistry, the use of pot and water cultures and plot tests, essentially the methods most used to-day. Although it was recognized by many that the addition of mineral substances to the soil frequently increased plant growth, and that the ashes of plants contained minerals, nevertheless the theory that found most favor and was most widely accepted is that known historically as the "humus" theory.

THE HUMUS THEORY.

The organic complex in the soil resulting from the decay of plant and animal tissues was generally supposed to be the main food of plants. It is similar in composition, and is (apparently, at least) affected in solubility by the addition of salts. It is certainly rendered more soluble by alkalies, hence by plant ash, and thus the action of mineral substances in improving plant growth could be explained. It has been recognized from time immemorial that soils rich in humus are as a class more productive than soils poor in humus. Without pausing to go into complete detail, it is read-

ily understandable that in times when syllogisms were more appreciated than laboratory or field experiments men's minds could easily accept the humus theory as the most plausible explanation of soil fertility.

The humus theory was the dominating one when, about 1840, Liebig commenced his investigations in agriculture and laid down the basis for a systematic, scientifically-developed branch of human knowledge, essential to mankind's happiness and welfare; namely, agricultural chemistry. Liebig's first important work in this field was a comprehensive examination of the validity of the humus theory by subjecting it to the tests of quantitative chemical analyses. He showed that humus was very slightly soluble in water, except in the presence of considerable amounts of alkali. Even freshly-precipitated humus was rendered less soluble either by drying or by freezing, hence changing weather conditions would render it less rather than more soluble. If insoluble in the soil water it can not be taken up by plants through their roots. To test the possible importance of alkalies in rendering the humus more soluble, Liebig computed the carbon content of soils and found there was far less than in the crops produced by the same soils. Furthermore, careful and proper cultivation resulted not only in larger crops, and hence more carbon in plant tissue being produced, but simultaneously there was an increase in humus and carbon in the soil. And, finally, he pointed out that if humus be the result of the decayed plant tissue, there must have been plants before there ever was any humus, which requires an explanation of how the primordial plants existed.

Liebig, having shown that the carbon of plant tissues can not come from the earth, pointed out that it must come from the air, and, as had already been made evident by the work of Priestley, Ingen-Housz, Senebier, and de Saussure, there is an absorption of carbon dioxide with liberation of oxygen by growing plants while in sunlight, with a reverse absorption of oxygen, with sometimes an elimination of carbon dioxide, when these same plants are in the dark. But Liebig went further and showed that the oxygen and hydrogen in plant tissues are present in about the same proportions as in water. De Saussure had already shown that water was taken up by plants and utilized in tissue formation. Hence, the oxygen taken up by carbon

dioxide being an unnecessary excess to the plant, its elimination is natural and to be expected. It follows that for every volume of carbon dioxide absorbed in the formation of plant tissue an equal volume of oxygen is added to the atmosphere. Liebig recognized that here was the explanation of the sustained constancy of the oxygen content and carbon dioxide content of the atmosphere, and that this continually-sustained interchange of oxygen and carbon dioxide by vegetation was necessary for the continued life of animals. He supported his arguments by analyses of air from old, long-buried vessels, from various other sources, and by computations of the probable duration of animal life if there were no such renewal of the oxygen supply. To the objection that the very small normal content of carbon dioxide in the atmosphere, less than one-tenth of one per cent., is insufficient for the support of vegetation (*i.e.*, its rate of growth), Liebig again brought the quantitative method. By determining the absorption of carbon dioxide on a surface washed with a lime suspension, he found that in a given time there was five or six times more carbon dioxide absorbed than was taken up by an equal area of leaf surface. From these deductions Liebig next made clear that the metabolic processes in plants and animals were essentially different. Although the contrary view, based on analogy, was the popular one, Liebig's great authority prevailed. The times were "ripe." A half century earlier, as we now know, Lavoisier had clearly seen the truth, but his opinions were not made public until many decades (1862) after his untimely murder. But Boussingault and Dumas, of scarcely less authority in scientific matters than Liebig, expressed similar views to his in 1841. And, in England especially, agriculture had become popularized with the better-educated and leisure classes, there was much discussion of agricultural subjects, and men's minds were receptive for the teachings of the great German savant, at that time very popular in England and with an immense prestige in the scientific circles of France.

MINERAL THEORY.

Having demolished the humus theory, Liebig turned his attention to the mineral constituents of plants. It had been noted by van Helmont, in his famous experiment already cited, that there was a small loss of the soil, and it was repeatedly

shown by subsequent investigators that plants contained mineral substances which remained in the ash when they were burned. It was also well known that plant ashes were alkaline, which was quite widely accepted as a proof, in early times, that plants generated or created alkalies. When Liebig began his work on agriculture the exponents of the humus theory, supported by so great an authority as Berzelius, recognizing the value of mineral substances when applied to the soil, explained them as stimulants, but not as plant foods or as essential to plant growth. Liebig immediately instituted, at the famous Giessen Laboratory, a long series of investigations of the composition of plant ashes and of the mineral content of soils. Meanwhile other workers were active, as Ville, the apostle of scientific agriculture in France, and Knop, famous because of his studies of plants in water cultures, with numerous earnest colleagues of equal distinction and importance. It was soon found that some nine or ten mineral constituents were always present in plants, and that plants could not be grown in artificial media unless these constituents were present, each and every one.

This led to the idea of supplying mineral plant food artificially to increase immediate plant production, to build up and increase the fertility of the soil, and to ward off soil exhaustion, etc., subjects quite familiar in the current writings of to-day, especially in connection with the great "conservation" movement now stirring the public consciousness and, let us hope, the public conscience.

The first "chemical manures," or commercial fertilizers, as we call them to-day, were prepared on the assumption that they should be of very slight solubility in water, that they might simulate the character of the natural soil components, and that they might not be leached from the soil too rapidly. In spite of many notable successes from their use, there were a great many disappointments and, on the whole, the results, especially in practical farm work, were far short of expectations. The experiments of Way suggested an explanation. It has been known, from the time of Aristotle at least, that soils are absorbents of mineral substances as well as of soluble organic materials. Way's quantitative investigation showed that many mineral substances were abstracted from water solutions or

"fixed" by the soil when the solution was percolated through the soil. Apparently, Way considered that in most cases there was a metathetical reaction between the soil components and the dissolved substance. Liebig followed up Way's work enthusiastically and vigorously, considering the fixation of the dissolved substance on the surface of the soil particles as due to a "physical combination," or, as we now term it, to adsorption. Water-soluble mineral fertilizers would be held in physical combination when applied to the soil, ready to reënter the soil water as it was depleted by the plants.

This idea also explained the disappointing results of soil analyses, where it was often found that soils which contained the larger percentages of mineral nutrients or "plant foods" were not always the more productive. Quickly there was developed the idea that there is a real distinction between the mineral nutrients *in toto* and the proportions which are "available," immediately or ultimately. A great many methods, frankly empirical and with very slight scientific basis, have been devised to analyze chemically the soil, usually by analyzing an extract obtained by heating the soil with an acidified aqueous solution. An enormous amount of data has been thus accumulated, unfortunately of very little value, either theoretically or practically. But this idea of availability has dominated by far the greater part of the chemical work on soils and plants for the half dozen decades succeeding Liebig's work, and we even hear to-day of chemically available, physically available, and biologically available plant food.

Of only lesser importance as a guide in soil work has been the so-called Liebig's "law of the minimum;" *i.e.*, if an essential mineral plant food be absent from a soil, or present in unavailable form, or available but below a certain minimum amount, it will determine the growth of plants on that soil, irrespective of the amounts of other mineral substances present. This "law" has also been broadened by some writers to cover water and even bacteria.

THE DYNAMIC VIEWPOINT.

Following the epoch-making work of Liebig, there has been an enormous amount of work, much of it of very great value, much of it like a great part of Liebig's own work, incorrect and doomed to oblivion or to renewed life in modified forms. For

instance, van Bemmelin, recognizing adsorption phenomena in soils, the crumbing and decrumbing of soils induced by various substances, to be very similar to flocculation phenomena in recognized colloids, advanced the idea that colloids are predominating components in soils; and this view has recently been very forcefully presented by Russell: "If we regard the mineral particles the skeleton of the soil, we must look upon the colloids as clothing it in many of its essential attributes." Unfortunately, no one has any clear, much less precise, idea as to what is a colloid, and Russell would be quite correct, though less impressive, perhaps, if instead of colloids he should say the very finely-divided components of the soil with their relatively enormous area of active surface.

Out of this great mass of scientific endeavor there have come a number of highly-developed and distinct branches of science; as, plant physiology, plant pathology, ecology, soil bacteriology, and soil chemistry and physics. All of them are concerned fundamentally with the theory of soil fertility. Following the common course of development in every natural science, these subjects have gradually been developed from static viewpoints to dynamic viewpoints, more or less consciously recognized. Apparently there has been an exception in the case of soil chemistry, owing to a too-narrow view of the plant-food theory of mineral nutrients, an overweening appreciation of the authority of Liebig, and an unreasonable dependence on the all-sufficiency of analytical chemistry. In reality, this subject has also reached the state of development where its problems must be attacked from the dynamic viewpoint; and very substantial progress has been made in this direction, as will be apparent from the following sketch of our present knowledge of soil phenomena.

First, consider the growing plant. From the very fact that the plant is growing, plant phenomena are phenomena of change; that is, they are of a dynamic character. The absorption of carbon dioxide by the leaves and its elaboration into organic tissue is a dynamic phenomenon. So, also, is the absorption of nutrients and other substances from the soil solution by the root system. In a living plant the root is continually moving through the soil by growth processes. If this movement be arrested or prevented the plant will soon die. Back of the root tip there is the area of absorption where the soil solution enters the plant.

The mechanism of the absorption is very far from being understood. Usually it is more or less glibly described as an osmotic process, leaving very much to be desired in the way of explanation. We know that organic residues of plant metabolism are left in the soil; that enzymes, probably for protective purposes, are developed by growing roots. We also know that all the mineral substances taken into the plant during its growth and development do not permanently remain therein, but are partly eliminated through leaf and partly, probably, by root excretion also. But all these phenomena are phenomena of change, are dynamic in character, and the comparatively rapid development of knowledge of plant processes in recent years has undoubtedly been due to the gradual acceptance of the dynamic viewpoint, whether consciously or unconsciously.

Defining soils, for convenience, as those areas of the solid surface of the earth adapted to the growth of crop plants, it has been found that each and every soil is quite complex in composition. There is an old generalization that everything ultimately finds itself in the sea. But on the way to the sea most things pause for a time in the soil. The products of every activity—natural and artificial—are likely to be found in any soil. And the presence of any or all of these products may have some influence on its capability for crop production.

Recent investigations have shown that practically every inorganic element for which reliable methods of analysis are available is to be found in the soil. In a very careful investigation of some twenty-seven soils of known agricultural importance from widely-separated points throughout the United States east of the Mississippi River it has been possible to make quantitative determinations of practically every mineral element excepting molybdenum, gold and platinum. Molybdenum was found in some soils but not recognized in others, and gold and platinum were not specially sought, as of no particular interest in this connection. As to the minerals themselves, it has been shown that practically every common rock-forming mineral is present in every soil. The mineral complexity of any soil is far greater than that of a rock, probably due in the main to the large aggregate amount of soil transportation by the wind.

Likewise, humus, or the mixture of organic *débris* in every soil supporting vegetation, is always complex. Some forty or

more definite organic compounds, containing representatives of practically every known type of organic substances, have now been extracted from soils. Existing knowledge of the complete composition of the humus of any particular soil is very far from complete. It is probable that certain organic substances will be found common to all or most soils, while other substances will have an adventitious significance only. But the number of distinct organic species in any one soil is probably quite large.

The solid components of the soil are in various stages of subdivision, from gravel down to particles so small as to defy the powers of the microscope to recognize their limits. These very fine particles, silt and clay, may comprise only a small percentage of the soil mass, as in sandy soils, or much more than half, as in heavy clays. Mechanical separates of soils, between arbitrary limits, have been analyzed, showing that there is a tendency towards segregation of the constituents in different-sized particles. Humus, ferric hydroxide, potassium, phosphoric acid, and, in fine, all those constituents of recognized importance to plant growth, tend to segregate in the finest particles. These finest particles, in the aggregate, have an enormous surface which is thus exposed to the action of the soil water, and which also accounts for the pronounced adsorptive powers of soils, or, as Liebig found, the ability to form "physical compounds," as distinguished from chemical compounds.

The solid components of the soil are continually in motion. The transport of the soil material by water is very great and striking in the case of such a river as the Mississippi. But it is proceeding on lesser scales everywhere. No field is so flat but that there is some movement of the surface particles with every rain, and it is obvious that erosion is proceeding everywhere on the land surface of the earth, rapidly in some places, more slowly at other points. But of little, if any, less importance is the transport of soil material by the wind, although this is not recognized generally by the lay public. If the attacking power of the wind on the soil were as great as its transporting ability—which fortunately is not the case—it has been computed that the amount of soil material which would be blown into the Gulf of Mexico from the Mississippi Valley would be 4000 times that carried down by the river. Testimony of the carrying powers of the winds is furnished by deposits of soil material, frequently sup-

porting plants, on roofs, barren mountain tops, glaciers in Greenland, etc. Samples have been brought back from the polar ice which have been found to be ordinary soil material. Dust from the Sahara is blown across the Mediterranean into Europe every year, and has been traced so often as to be quite familiar. The most striking case, perhaps, is the Alaskan tundra, where a foot or two of soil material, supporting a luxuriant vegetation, is underlaid by perennial ice. No agency other than transport by the wind can explain the presence of this soil material. It is well known now that it is the common condition that the surface soil is lighter than the subsoil, due mainly to the fact that the finer soil particles have been blown out of the surface material. Moreover, the wind is in action all the time, or practically so, and carries material up hill as well as down. Soil material is continually being transported, deposited, and retransported, so that there is little wonder that soils are such heterogeneous mixtures. And, again, it is to be noted, it is the finest particles which are the most important in affecting crop growth which are the most subject to transport by water and wind.

There is another movement of the solid particles of the soil. It has been shown that every observable physical property of the soil which can be measured and which affects crop production is dependent upon the moisture content of the soil. If an air-dry soil mass be moistened, it expands or "swells up," and, as further moisture is added, the swelling continues until a certain moisture content is reached, after which further additions of water produce a rapid diminution of volume. Reversing the process (that is, drying out the wetted soil), there is first an increase of volume until the critical moisture content is reached, and then a gradual decrease. But the drying process does not follow the same path as the wetting process. There is an hysteresis, and continued alternate wetting and drying of the soil produces a natural packing of the soil material, such as must be taking place in the field with every cultivated soil. This is illustrated by the curves of Fig. 1. The only rational explanation of this hysteresis is that the soil particles move about among themselves with rearrangements of structure following change of moisture content. In the field the moisture content of the soil must be continually changing with the weather, hence

the soil particles must be continually in motion. Drying of the soil produces cracks, into which drops surface soil from the edges. Earthworms, beetles, and other organisms are continually transporting soil material. Movements associated with crumbing and decrumbing, and possibly other movements, are continually taking place. The soil particles must therefore be continually in motion, there must be more or less interchange of surface soil and subsoil taking place, and there must be more or less transport of soil material from place to place continually occurring. Of course, much of the most important part of the soil mass, from an agricultural point of view, is continually being lost in the sea and its tributaries, which loss is being met by the

FIG. 1.

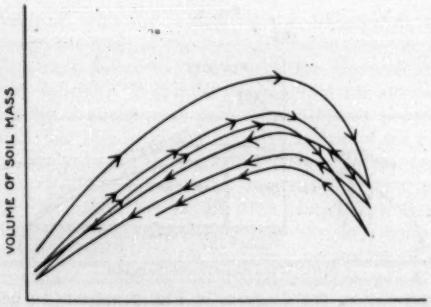


Diagram showing volume changes in a soil sample subjected to alternate wetting and drying. The arrows note the direction of the process. There is a "hysteresis" evidenced and a "natural packing" of the soil.

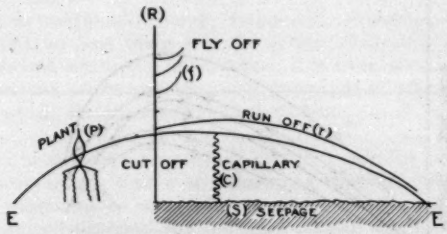
continual conversion of subsoil material into surface soil, through well-recognized agencies. It is clear that any and all phenomena involving the solid particles of the soil are phenomena involving continual change; hence they are dynamic in character.

There is, in every soil in proper condition for the growth of plants, an aqueous solution of the solid and gaseous components. This solution is, normally, disposed in the soil in the finer capillary spaces, but mainly in the form of films over the soil particles and aggregates of particles. At the critical or optimum water content the soil contains the maximum amount of water which it can, all the water being in films. Any increase

of water to the soil means some free water in the interstices, decrease of aëration, and a lessening of the optimum condition for plant growth. Any decrease of moisture below the critical moisture content means a redistribution and thinning of the films, with changes of stress on the floccules and a tendency to readjust the structure of the soil. Since, as noted above, the soil is always getting wetted or is drying out, there must be a continual movement of the soil solution, with continual change of stress, and more or less movement of the solid particles. Obviously the phenomena are dynamic.

The water forming the soil solution comes, of course, from the rain falling upon the soil. It will be well, therefore, at this point to consider the distribution of the rainfall; and, for clear-

FIG. 2.



Sketch of the disposition of the rainfall.

ness of exposition, the diagram in Fig. 2 appears to be useful. Let the line *EE* represent the surface of the soil, and the line *R* represent the rainfall (*R*). During precipitation there is a partial conversion of the rain to vapor, which the late Major Powell designated as the fly-off (*f*) in distinction from the run-off (*r*), or that portion of the rainfall which passes over the surface to the drainage channels. A part of the rainfall passes *into* the soil, going through the larger soil openings and moving at a rapid rate relatively, mainly under the influence of gravity. Consistently with Major Powell's terminology, this portion of the rainfall may be called the cut-off. In the soil the cut-off may be considered to divide into two portions. One of these, the seepage (*S*), moves through the soil at a rate determined by the character of the soil material, but relatively rapidly, and appears at the surface as a spring or bog or in some such way. More

or less mineral and organic matter is dissolved by the seepage water, so that all springs, ponds, lakes, rivers, etc., are soil solutions more or less diluted. But when the rain ceases there is an evaporation at the surface of the soil mass, a capillary drag or pull on the soil films is created, the resultant of the stresses being in the direction of the surface, and part of the cut-off water returns to the surface as capillary water (C), to ultimately join the fly-off. This rise of the capillary water is, in general, relatively much slower than the descent of the cut-off water and the movement of the seepage. Restating this description of the disposition of the rainfall in the form of an equation, we have:

$$R = f + r + \text{cut-off}$$
$$= f + r + s + C$$

But the run-off, plus the seepage, is the drainage of the area. The drainage for most of the large cultivable areas of the earth surface has been found to be not very far from 26 or 27 per cent. of the rainfall. It is quite possible that for any particular small area the drainage may be a quite different percentage of the rainfall; but it is evident, from the nature of the case, that in general the drainage throughout a region can not vary much from the general average for that region. Likewise, while the fly-off may be a large percentage of a particular shower, or of the total rainfall in an arid region, generally, in a humid region it will aggregate but an almost vanishing percentage of the total annual rainfall. Assuming that the drainage and fly-off together may sometimes approach as much as one-third the rainfall, it then follows, from the equation given above, that C, or the capillary water, is equal to, or greater than, two-thirds of the rainfall. Such measurements as have been attempted indicate that on well-cultivated soils more than three-fourths of the rainfall not only enters the soil but again returns to the surface. It is evident that from the moment the rain-water strikes the surface of the earth until it either reaches the sea or evaporates into the air above the soil it is continually in motion, and all phenomena concerned with the soil moisture are of necessity dynamic in character.

Of the very many interesting and important consequences as well as speculations resulting from this consideration of the distribution of the rainfall, neither space nor time will permit description or discussion of more than one. Consider for a moment the plant illustrated by P in Fig. 2. Observe that the roots oc-

cupy but a small volume of soil near the surface, but that there is a stream of capillary water from the subsoil moving past the roots and bringing to them mineral substances in solution derived perhaps from minerals at considerable depths below the surface. In other words, during the growing season the principal supply of mineral nutrients used by the plant in its metabolic processes is derived probably from the subsoil, where the plant roots never penetrate. The faster the plant grows the faster it dries out the moisture along the roots, increases the capillary "pull," and thus automatically increases its food supply. It is clear, therefore, in spite of the popular notion to the contrary, that a chemical analysis of a small sample of surface soil is not an adequate or scientific method of determining the plant's food requirements. Yet this procedure has been the basis for much, if not most, of the experimental work on the fertilizer requirements of soils and of plants.

A consideration of the composition and concentration of the soil solution naturally follows. On its way through the soil to the surface the capillary water is in intimate contact with the solid soil particles for considerable time intervals, and these particles are composed of a large number of substances, inorganic and organic. Hence the soil solution is a somewhat complex one, and the solution products of the soil and subsoil are subject to a tendency towards concentration at the surface or in the upper soil layers. During a period of drought this accumulation of soluble materials may become quite pronounced, and in arid regions surface accumulations of salt mixtures known as "alkali" are unfortunately common. In humid regions, however, every rain carries back more or less of the accumulated soluble material in the cut-off water to the lower soil levels, where it may recommence its relatively slow ascent towards the surface.

Most of the definite mineral species found in soils may be regarded as salts very slightly soluble in water; and, usually, they are salts of a strong base, such as calcium or potassium, combined with a weak acid, a silicic or an alumino-silicic or ferro-silicic acid. A good illustration, for various reasons, is the mineral orthoclase which may be represented by the formula $KAlSi_3O_8$. Because of the nature of these salts, the dissolved portion is greatly hydrolized, thus:

$$KAlSi_3O_8 \longrightarrow KOH + H_1AlSi_3O_8$$
$$\longrightarrow KOH + SiO_2 + H_1AlSi_2O_6$$
$$\longrightarrow KOH + 2SiO_2 + H_1AlSiO_4$$
$$\longrightarrow KOH + 3SiO_2 + HAlO_2$$

The acid $HAlSi_3O_8$ is not known, but all the other compounds indicated are known as natural minerals and as alteration products of feldspar. It is by some such process as here indicated that most of the mineral plant nutrients in the soil solution are derived originally. But it is obvious that the concentration of the soil solution, if this were the only phenomena involved, could never be other than very small, except for temporary high concentrations near the surface of the soil during periods of prolonged drought.

Consider now the "physical compounds" first recognized by Liebig and justly regarded by him as of primary importance to soil fertility. These are far better understood nowadays as adsorption complexes. It is recognized that any solid surface, speaking generally, possesses the power to withdraw from a solution in contact with the surface and condense upon itself more or less of the dissolved components in the solution. Adsorption is a phenomenon dependent primarily upon the specific properties of the substances involved. But always there is a distribution of the soluble substance between the solvent and the absorbent, and, as one concentration changes, coincidentally there is a change in the same direction in the other concentration. For instance, if a soluble potassium salt be added to a soil in good moisture condition there will be an increase in the concentration of the soil solution, but at the same time there will be an increase in the concentration of the adsorbed potassium on the surfaces of the soil particles. Not only is the specific adsorption of the soil surfaces very high for most components of importance to plant growth (an interesting exception being nitric nitrogen), but the amount of adsorbing surface exposed by the soil particles is relatively enormous as compared with the volume of water in the soil solution. Hence, speaking generally, it would be necessary to add a great deal of a soluble salt, far more than is practicable in general farming operations, to produce a change in the concentration of the soil solution sufficient to be detected in any other way than by the response of a growing plant. It may be noted, in passing, that the growing plant

is a far more sensitive instrument than any of man's devising.

The importance of this subject justifies a repetition of the above argument in a somewhat different form. Consider again, for convenience's sake, the concrete case of soluble potassium in a soil at optimum water content. As the soil dries out there is a concentration of potassium in the remaining solution, which might easily reach a point where it would be actually toxic to plants, were it not for the fact that the relatively great adsorbing surface of the soil must simultaneously increase concentration also with respect to the potassium, so that the actual change in the liquid phase is quite small and is gradual. But that these small gradual changes are taking place continuously is beyond doubt.

Since Liebig's time, another class of substances has come to be well recognized, namely, solid solutions; that is, homogeneous mixtures in the solid state which can not be separated by mechanical means and which, unlike definite compounds, may vary gradually in composition with a corresponding gradual change in properties. Solid solutions are probably of great significance in soil phenomena. For instance, it is probable that most of the phosphoric acid in the soil is in the form of solid solutions. If a solid solution be in contact with a liquid solution and they both contain a common constituent, then every variation of the concentration of the common constituent in the one solution necessitates a corresponding variation in the concentration of the other solution. In general, and certainly with such cases as can reasonably be expected to exist in soils, a very considerable variation in the concentration of the solid solution corresponds to a much smaller variation in the liquid solution. Thus the addition of a large amount of a soluble phosphate to a soil might temporarily produce a considerable increase in the concentration of the soil solution, but only temporarily, for very quickly most of the phosphoric acid would be absorbed by the relatively large mass of ferruginous material present in soils to form a solid solution; *i.e.*, basic ferric phosphate.

Thus, as regards the composition of the soil solution, the concentration of the several constituents and components is continually changing, and the phenomena are dynamic, for what has been presented here holds for organic as well as inorganic substances.

To trace in a similar way the phenomena of the soil atmosphere and the living organisms within the soil would necessitate going far beyond the reasonable bounds of a lecture. Suffice it to call attention here to the quite obvious fact that all the phenomena these subjects call to mind are of a dynamic character.

SOIL MANAGEMENT.

Consider now the fundamental problem of soil management; namely, the production of a crop (C). This depends on certain factors which are variables—upon:

(R) The rainfall. Not only as to amount, but as to distribution.

(S) The sunlight. Again, with regard to distribution as well as amount.

(P) The plant itself. For there is great variation between a potato, let us say, and a wheat plant or a cherry tree.

(p) The physical properties of the soil.

(c) The chemical properties of the soil. Not alone as to the mineral nutrients or so-called "plant foods," but of all the chemical processes, organic as well as inorganic, taking place, and especially, perhaps, the balance between oxidation and reduction processes.

(b) The biological properties of the soil, including not only the now familiar bacterial flora, but enzymes and moulds which are common, if not necessary, accompaniments of cultivated crops; the adaptability of the soil as a habitat for earthworms, insects, etc.

Besides these so-called natural factors, and perhaps others which we dimly suspect without being able to definitely formulate, there are three artificial factors, the products of man's ingenuity, namely:

(T) Tillage operations;

(R) Crop rotations; and

(F) Fertilizers.

Gathering these factors together in mathematical form, for convenience's sake, they may be written:

$$C = \int (R, S, P, p, c, b, \ldots\ldots F, T, R).$$

For the solving of such a function there are two possibilities:

First, if the variables are independent of one another, they can all be made constant but one. This is the assumption very generally made in the past by experimenters with pots and plots; and the rigid adherents to the plant-food theory of fertilizers have implicitly assumed further that the function is linear (that is, the simplest possible), which it certainly is not. Fertilizer responses by crops should be strictly additive, which they are not.

Second, if the variables are dependent (that is, mutually affect one another), then it will be necessary to determine these interrelations before one can substitute their equivalents and solve the function, even qualitatively. That the variables are all dependent will be obvious on even a cursory survey of existing knowledge. Consider, for example, the plant factor, *P*. It is obviously affected by the amount and distribution of the rainfall and of sunshine. Root penetration is affected by the tilth and the physical factors. Growth is certainly affected by the balance between bacterial flora, the types of moulds developed in the soil, and the balance between oxidation and reduction processes, and certainly by the composition of the soil solution and its movement in the soil. These factors are in turn all affected by the tillage, the crop rotation, and the fertilizers. A mineral salt added to the soil probably produces effects larger in degree and as important in kind on the crumbing and decrumbing of soils and the other physical factors as on the chemical properties. It directly or indirectly influences the development of the various types of bacteria and other organisms. It influences the aëration, the movements and distribution of the soil solution, root penetration, and root absorptions.

It is a recognition of the interdependence of these variables that marks the first important step towards a really scientific development of the important art of soil management or crop production. Meanwhile it may not be amiss to point out the practical usefulness of this formulation. Consider a case from actual experience: a farmer who planted a rather heavy clay loam to wheat, and, being advised that his soil was "deficient" in potash, applied a generous amount of wood ashes for their

content of potassium carbonate. Undoubtedly he increased the amount of "plant food" thereby, but the potassium carbonate, being decidedly alkaline, puddled his heavy soil, impeded root penetration, retarded the movement of moisture, thus cut down absorption of solar radiation, and made a cold soil. Aëration being poor, there was an abnormal development of unaërobic bacteria, and, in fine, the crop was poor, as might have been anticipated. If he had used potassium sulphate, on the other hand, he might have anticipated a greater selective absorption of potassium than of sulphion by both soil and plant, and a slight acidifying of the soil solution. If not too great, this would have stimulated root development, would have induced crumbing and better tilth, and possibly bad effects on plant and biological factors could be obviated by a light dressing of lime, which, unlike other alkalies, has a flocculating effect. The lime would have been even more desirable if he had used potassium chloride.

Again, take the case of tomatoes on a light, sandy loam, where it was proposed to use heavy applications of sodium nitrate. There is a very marked selective adsorption by soils in the case of this salt, sodium being strongly adsorbed and nitric acid very little adsorbed. But, on the other hand, nitric nitrogen is very quickly absorbed by growing plants, which give a very marked response in increased leaf development. On a sandy loam, therefore, the tomatoes would be expected to make a very rapid growth, with the aërial portion of the plant out of proportion to the roots. A short spell of hot weather might then produce disastrous wilting. The accumulation of the free alkali sodium as carbonate and bicarbonate near the root crown might cause serious injury to the bark, and in an actual case there was a serious baking of the surface soil, induced partly, no doubt, by the puddling action of the too strongly-alkaline residue. Without following the case further, it will be seen that a chance of a successful crop is not alluring. A similar analysis for ammonium sulphate also indicates a doubtful success. It would have been better to have depended largely upon an organic nitrogen carrier, with good tillage to induce proper bacterial activities, and to have supplemented this by occasional light applications of sodium nitrate or ammonium sulphate as the condition of the growing crop might indicate.

Returning to theoretical considerations, it would be noted

that the equation is not one of state, but an equation of motion, since, from what has been pointed out already, every one of the natural factors is continually in a process of change. The problems of soil management are therefore essentially dynamic. Moreover, when it is considered that the soil is made up of a large number of components, and that the properties of the soil are not merely the sum of the properties of the components, but the summation of these properties as they mutually affect and modify each other, it becomes evident that a particular soil is a system pretty high in the scale of complexity, and that the differences between soils become of relatively more importance than the similarities and common properties. In other words, soils must be considered as individuals. And nothing that is done to one soil can be expected to make it the same as another soil, not even in crop-producing powers, except by a meaningless accident.

The time has now arrived when it must be recognized that the problems of soil fertility are no longer problems merely of soil composition or merely of a supply of plant food. The great fundamental questions now are, not what things are in a soil, but, What are the processes—physical, chemical, and biological—taking place continually in the soil? What are their magnitudes, and what are the rates of change? How do they affect one another? What are the *differences* between individual soils that are the expression of the resultants of these interdependent processes?

To-day we have partial answers to these questions. To-morrow the answers will be fuller and more nearly complete. But they will inevitably raise new questions. Meanwhile the art of soil management will develop and improve as our knowledge of the factors involved gives us a more intelligent control of them. It is ridiculous to be satisfied with a yield of fifteen or even fifty bushels of wheat to the acre when, under controlled conditions in a greenhouse, wheat has been raised to the extent of upwards of 160 bushels to the acre.

But it is not the purpose of this lecture to speculate on the future possibilities of agriculture, no more than it is to give a complete review of existing knowledge regarding soil fertility. Only a small number of the "high points" can be noted. But enough of these have been touched, it is hoped, to demonstrate that there has been a steady progress from van Helmont's time

to the present; that, as Liebig's work was a necessary and logical development of the work of his predecessors, although at the time it appeared startling and was provocative of bitter contentions, so the development of the dynamic viewpoint as sketched here is but a logical and necessary consequence of the work since Liebig. Before Liebig many mistakes were made, but some truth was found. Liebig made many more mistakes, but he added much to the store of truth. Since then, doubtless, much that has been done and said will prove mistaken or of little worth; but out of it all we can confidently believe that the store of true knowledge has greatly grown and that our vision is wider and more trustworthy.

The increase of human knowledge in every field of scientific inquiry appears, at close range, to go forward *per saltem*, and it is sometimes hard for the individual scientist to take the leap. But, looked at from a proper perspective, there appears to be a smooth and regular progression. Thus the recognition of the dynamic viewpoint of soil fertility merely marks a convenient point on the curve representing the steady growth of knowledge in a field of inquiry of fundamental importance to the happiness of the human race.

Submarine Oil Pipe-lines. P. C. A. STEWART. (*Journal of the Royal Society of Arts*, vol. lxiv, No. 3287, November 19, 1915.)—Owing to the unfavorable nature of the comparatively shallow water close in to the coast, the Mexican Eagle Oil Company originated the idea of laying submarine pipe-lines to points where the largest tankers could be conveniently moored for loading purposes at any state of the tide and weather. They have three deep-sea loading berths at Tuxpam Bar with duplicate pipe-lines to each berth; the Penn Mexican Fuel Company also has two loading berths equipped with pipe-lines in duplicate. The lines terminate in 43 feet of water, which is below wave-action, and at the point where the pipe ends 120 feet of armored flexible hose is attached. The free end of the hose is closed by a blank flange and allowed to lie on the sea-bottom when not in use, its position being marked by a buoy with a chain sufficiently strong to lift it.

The rise and fall of the tide is approximately two feet, so that the depth of water, 43 feet, is sufficient for the largest tank steamers to load at any time. Tankers of 15,000 tons dead weight, drawing 28 feet, are regularly loaded.

Electric Heating and Cooking. P. W. GUMAER. (*Scientific American*, vol. cxiii, No. 23, December 4, 1915.)—A new type of heating unit has recently been devised for electric-heating devices. The high-resistance wire through which the electric current flows is enclosed in a steel sheath, and insulated therefrom by a material which will withstand excessively high temperatures without deterioration. The core wire and powdered insulation are inserted in the sheath when the three are large in diameter. They are then rolled and swaged to the proper size. By an ingenious arrangement the ends or terminals of the unit are left large in diameter. This facilitates the attachment of terminal connections and permits the terminal to operate at a low temperature. The outside metal sheath protects the core wire from oxidation when operated at high temperatures, as air can not penetrate through the sheath and as the core wire is large in cross-section and comparatively cool where it is exposed to the air.

This type of heating unit lends itself readily to the construction of a hot-plate or stove which is practically ideal. The sheathed wire is arranged in a flat coil and molten iron is cast around it. The result is a heating unit which is rugged and durable as an old-fashioned stove-lid. Good thermal contact is obtained from the resistance wire through the sheath to the cast iron. The low thermal resistance path for the heat and a heat-insulating pad beneath the unit secure an especially high efficiency.

Modern Electric Elevators and Elevator Problems. D. LINDQUIST. (*Proceedings American Society of Mechanical Engineers*, New York, December 7th to 10th, 1915.)—The elevator art has gone through quite a number of more or less radical changes in the last fifteen years. These changes have been partly due to developments in building construction, making it possible and practicable to erect high structures. Elevators may be classified according to the driving power employed: steam-driven, hydraulic, and electric. The first class is now practically obsolete. Hydraulic elevators may be divided into several groups, depending upon the different methods by which the hydraulic power is applied to the car. The principal and well-known types in common use are the horizontal hydraulic (rope-geared), the vertical hydraulic (rope-geared), and the plunger hydraulic (direct-connected). These were introduced in the order named for high speed in comparatively high buildings. The plunger type practically superseded other types of hydraulic elevators during the period of 1904 to 1907. Now, in turn, the plunger has been almost entirely superseded by the gearless "one to one" type of electric elevator. The electric achievement in the design of a motor capable of operating efficiently at 60 revolutions per minute and less is responsible for this radical design of elevator drive. Incidentally this design affords unusual opportunities for interesting and very efficient methods of braking and control.

A 32-ELEMENT HARMONIC SYNTHESIZER.*

BY

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HARMONIC ANALYSIS AND SYNTHESIS.

THE harmonic method of analysis based upon Fourier's Theorem, first published in "La Théorie Analytique de la Chaleur" (Paris, 1822),[1] is of the greatest value in the investigation of many curves, and especially of periodic curves which represent wave motion. The method has been successfully applied in many branches of science, such as acoustics, electricity, magnetism, heat, optics, astronomy, mathematics, tidal phenomena, meteorology, seismology, naval architecture, statistics, and mechanical engineering. This theorem may be stated as follows: If any curve be given, having a wave-length l, the same curve can always be reproduced, and in one particular way only, by compounding simple harmonic curves of suitable amplitudes and phases, in general infinite number, having the same axis, and having wave-lengths of l, $\frac{1}{2}l$, $\frac{1}{3}l$, and successive aliquot parts of l. The given curve may have any arbitrary form whatever, including any number of straight portions, provided that the ordinate of the curve is always finite and that the projection on the axis of a point describing the curve moves always in the same direction. The significance of this theorem as applied to particular curves is explained and graphically illustrated in other parts of this paper.

Fourier gave a complete method of analysis by numerical calculation for determining the exact size and position of the component simple curves required to represent the given curve. The calculation, which is very laborious, involves the evaluation of a large number of "definite integrals," each of which is of the nature of an area. It has been found possible to measure the areas pertaining to a given curve (that is, to evaluate the definite integrals involved in the Fourier equation) by tracing the curve with mechanical integrators known as *planimeters*. A complete apparatus arranged for the purpose of mechanically deriving the Fourier equation of a curve is called a *harmonic analyzer*.

* Communicated by the Author.

The first harmonic analyzer was devised by Lord Kelvin, about 1872, in the development of a method for predicting the tides. The rising and falling of the tides at any locality, having been observed for a period of time, as for a year or more, is represented by a curve. Such a curve is the resultant of a number of periodic factors and is, therefore, suitable for harmonic analysis. The periods are determined by theory, but the amplitudes and phases are found by analyzing the observed curve. The periods of the tidal components are not related to one another in simple ratios (that is, they are inharmonic in time), but the method of analysis is, nevertheless, applicable, as each tidal curve is compounded of separate curves, each of which is a simple harmonic curve. Lord Kelvin's analyzer[2] is based upon the rolling sphere-and-cylinder integrator devised by his brother, James Thomson.[3] The original instrument is now in the museum at South Kensington, London. Numerous other analyzers, suitable for general or special purposes and using various types of integrators, have been devised, that of Henrici being perhaps the most precise and convenient.[4]

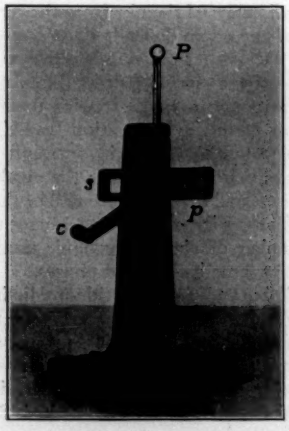
The observed tidal curve, for a given station, having been resolved into its simple elements, the prediction of the tides requires the recompounding of these elements under the given conditions relating to the future date. If the resultant is represented by a curve, the high tides and the low tides are directly shown and can be measured and the time of occurrence can be specified. The compounding of the elements can be done numerically in some instances, and can always be accomplished graphically. As is the case in analysis, these operations are laborious, and Lord Kelvin and others have constructed machines for drawing the composite curves; such machines are called *harmonic synthesizers*.

Lord Kelvin's harmonic synthesizer is based upon an old mechanical movement (Fig. 1), known as the pin-and-slot device. When the crank c is turned with uniform angular speed, the pin p causes the frame s and all attached parts, as the point P, to move up and down with *simple harmonic motion*.

The usual starting point in describing such motion is the middle position of P when it is about to move upward; that is, when the crank is horizontal with the pin p at the extreme right and about to turn counterclockwise. One *complete vibration* is

produced when the point P moves from its mid-position to the upper position, to the lower extreme, and back to mid-position; that is, when the crank makes one complete revolution. The *frequency* is the number of complete vibrations, or revolutions of the crank, per second; the *period* is the time required for one complete vibration. The *phase* at any instant is the fraction of a period which has elapsed since the point last passed through the starting point, and is often expressed by the number of degrees which represents the position of the crank-pin as referred to its

FIG. 1.



Pin-and-slot device for producing simple harmonic motion.

initial position. The *amplitude* is the range in one direction or the other from the middle point of the motion of P; therefore, it is half the extreme range of the vibration, and it is measured by the length of the crank from the centre to the pin p.

The first suggestion for compounding several simple harmonic motions so produced was made by Rev. F. Bashforth, in 1845,[5] and Lord Kelvin made the first machine, known as a *tide predictor*, under the auspices of the British Association for the Advancement of Science, in 1873.[6] The principles involved are

shown by the apparatus represented in Fig. 2. A cord *c*, fixed at one end, passes around several pulleys, and at the other end is attached to a pencil *p*, which makes a trace on a moving chart. The pulley *a* is attached to a pin-and-slot device, which moves up and down with a simple harmonic motion. The cord transmits this motion to the pencil, doubled in amount. If the chart moves horizontally with a uniform motion, the trace is a simple harmonic curve; this curve, also called a *sine curve*, represents the simplest possible wave motion. The frequency of the motion, or the number of waves per second, depends upon the rapidity with which the crank-pin is rotated, and the amplitude of the wave depends upon the distance of the pin from the centre of its crank; the *wave-length* of the curve depends upon the speed with which the chart moves. If another pulley *b* is attached to a second pin-and-slot device rotating twice as fast as the first, it will give the pencil a simple harmonic motion of twice the frequency of the first. It is evident from the illustration that if the two devices operate simultaneously the cord will transmit to the pencil a composite motion which is at all times the algebraic sum of the two separate motions, and that the trace will be the synthetic curve of the two simple harmonic curves. The scheme may be extended to include any number of simple harmonic motions having any specified frequencies, amplitudes, and phases.

A most remarkable and elaborate tide-predicting machine with 38 elements, based upon these principles, has been constructed by the United States Coast and Geodetic Survey. A complete description of this machine and brief descriptions of all other tide predictors, beginning with that of Lord Kelvin, are given in "Special Publication No. 32" of the United States Coast and Geodetic Survey.[7]

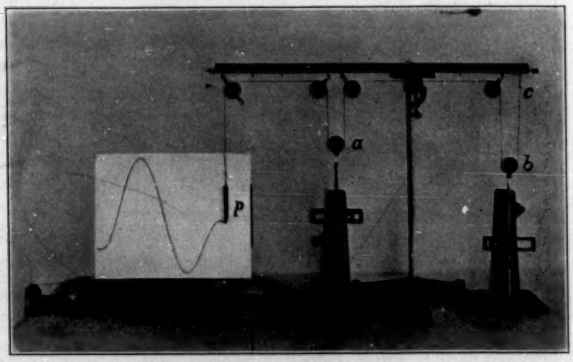
Other methods of harmonic synthesis have been devised. Professor A. A. Michelson has made a machine with 80 elements in which the harmonic components are represented by the tensions of springs; this instrument may also be used as an analyzer.[8] Machines employing gear wheels have been constructed, but these are usually limited to a few elements.[9]

A 32-ELEMENT SYNTHESIZER.

For some time the writer has been engaged in an investigation of photographic records of sounds by the method of harmonic analysis.[10] The analyses have been made with a Henrici har-

monic analyzer. As provided by its maker, this instrument is limited to the determination of ten components of the curves. By an addition to the analyzer, its operation has been extended to include thirty components. The nature of this alteration will be described later in this journal. Thousands of curves containing from ten to thirty components have been thus analyzed. The correctness and sufficiency of these analyses can best be proved by synthetically combining the elements given by the analysis. The synthesis should exactly reproduce the original curve. For this purpose, a harmonic synthesizer of ten elements, based upon the

FIG. 2.



Apparatus for illustrating the principles of the harmonic synthesizer.

pin-and-slot device was constructed in 1910. This instrument was soon found inadequate for the study of musical sounds, and was dismounted in 1914 upon the completion of the 32-element synthesizer, shown in Fig. 3.

This instrument, which is perhaps the most complete and convenient harmonic synthesizer of general application yet constructed, was designed and built in the laboratory and instrument shop of the Department of Physics of Case School of Applied Science. The Henrici analyzer requires that all curves for analysis shall be drawn to the wave-length of exactly 400 millimetres (about 16 inches), and the synthesizer has been constructed to

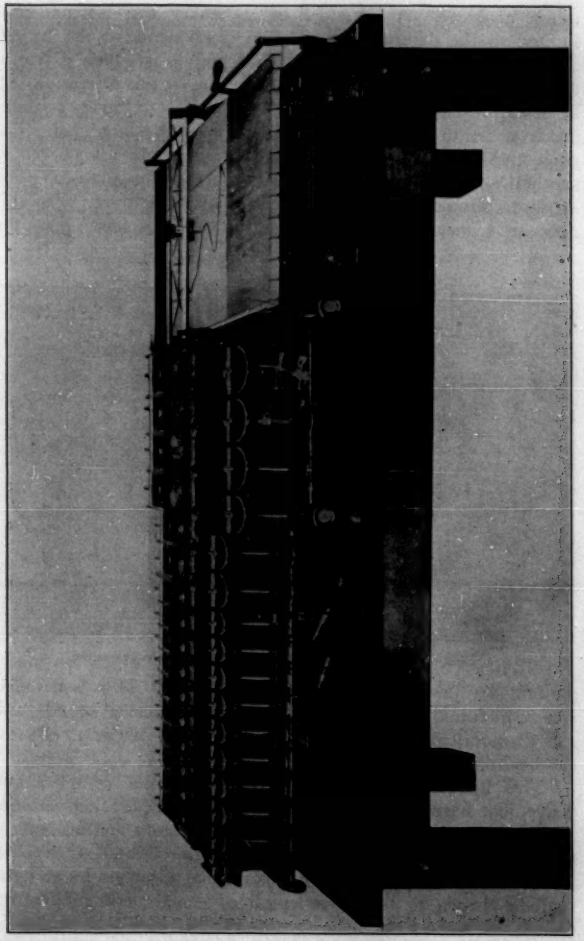


FIG. 3.

Harmonic synthesizer for graphically compounding 32 simple curves.

reproduce curves upon this large scale. It is also arranged for other wave-lengths.

With the larger wave-lengths it may happen that one or two components of a curve will have amplitudes of 200 millimetres (8 inches) or more. Usually only components of lower order are large, and the scheme adopted for this machine provides for amplitudes up to 340 millimetres (13 inches) for any one of the first six components, the other five amplitudes not exceeding 100 millimetres each at the same time. The diameter of each disk of the pin-and-slot device must be a little greater than the maximum amplitude of the corresponding component. To have provided for amplitudes of 300 millimetres, or even of 200 millimetres, for the first six components, would have made the completed machine large and cumbersome. Instead of six disks 300 millimetres in diameter (12 inches) for the first six elements, together with correspondingly large sliders and long strokes for the chain pulleys, six disks about 100 millimetres (4 inches) in diameter were used, and two additional disks 112 millimetres in diameter are provided, one or both of which can be made to supplement any one of the six disks. Since the disks are arranged on opposite sides of the main frame, in pairs, this saves more than 24 inches in the length of the machine and more than 32 inches in the width.

The dimensions chosen for the various parts, as described later, require a base for the instrument which measures 38 by 87 inches. This base is in the form of a table built especially for the purpose; the supporting parts are of oak, held in shape by stay-bolts, while the top is of cast iron in one piece, weighing about 500 pounds. There are several crossed ribs, about three inches deep, cast on the under side, which stiffen the plate. The machine rests on 24 bosses, the upper surfaces of which have been machined to one plane, while the plate was supported on three points—two at the corners on one end and one at the middle of the opposite edge. The plate in its final position as the top of the table is supported on the same three points only.

THE INTEGRATING ELEMENTS.

After the number and sizes of the elements have been determined, the next consideration is the convenient setting of the amplitudes and phases. This is especially important where hun-

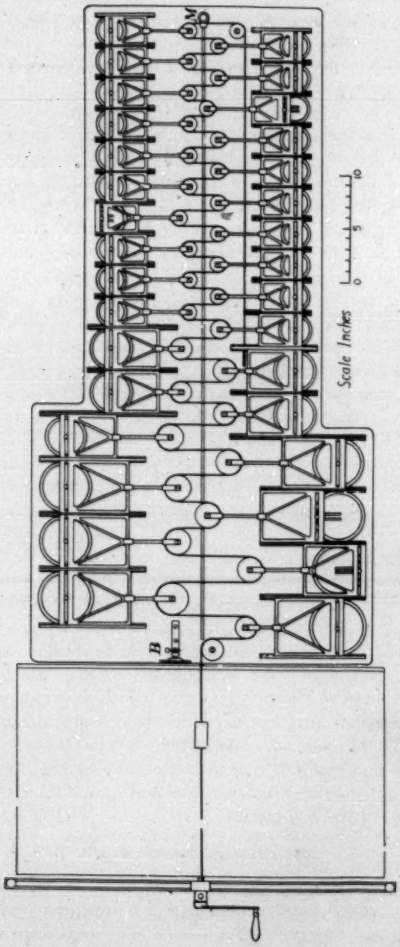
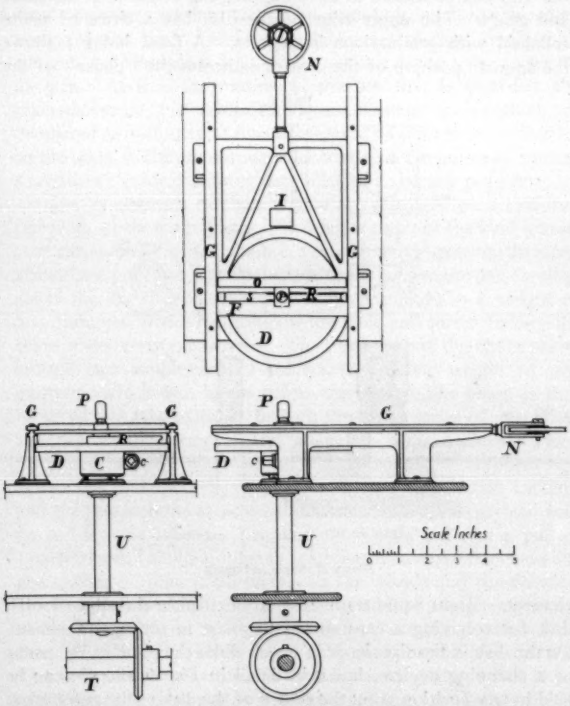


FIG. 4.

Top plan of the 32 integrating elements of the synthesizer.

dreds of curves are to be synthesized in succession. The disks are arranged horizontally along the outer edges of the main frame, as shown in Figs. 3 and 4, while the drawing-board which

FIG. 5.

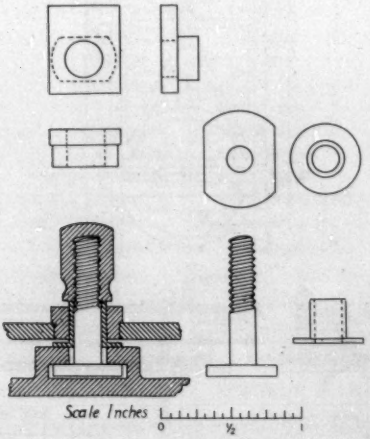


Details of one pin-and-slot element.

carries the chart on which the curve is to be traced is placed at the end near the larger elements. Before explaining the plan of the machine, the details of a single pin-and-slot element will be described.

The vertical shaft *D*, Fig. 5, is permanently geared to the driving shaft *T*. Attached to the upper end of the shaft is a cup-clutch *C* with a clamping screw *c*. The disk *D* has a hub which accurately fits the cup-clutch. By loosening the screw *c*, the disk can be turned to have any angular relation to the shaft and gears. The upper edge of the disk has a circle of white celluloid with graduations in degrees. A fixed index *I* shows the angular position of the disk or indicates the "phase" of the

FIG. 6.



Details of the pin and clamp.

element. Eight equidistant holes are drilled in the edge of each disk for receiving a capstan pin to assist in setting the phases. On the disk is a radial slot *R* in which slides the pin *P*. By means of a clamping device, shown in detail in Fig. 6, the pin can be held in any position from the centre of the disk to the outer edge.

The pin fits a hole in the centre of a small rectangular block of steel which slides in the slot *S* of the frame *F*. The frame *F* is movable to and fro between the parallel guides *G*. The sliding block in the slots carries a celluloid index which indicates the eccentricity of the pin on a graduated scale *O* of celluloid. A

pulley N is attached to the frame by a connecting rod. When the pin P is at the centre of the disk, the rotation of the disk produces no motion in the frame, but when the pin is set to one side of the centre the pin moves in a circle and, sliding back and forth in the slot of the frame, causes the frame and the pulley to move with simple harmonic motion, having an amplitude equal to the eccentricity of the pin. This simple harmonic motion, doubled in amount, is transmitted by a chain passing around the pulley to the pen. As it is the motion of the pen that is recorded, the graduated scale O is divided into half-millimetre spaces which are numbered as millimetres; thus the desired amplitude is set directly on the scale. The pin through the centre of the pulley N runs in a rectilinear guide, retaining the pulley in its proper position.

The 32 elements of the machine are arranged on a cast-iron bed-plate, as shown in Fig. 4. A flexible chain of the kind known as "chronometer fusee chain," 1/16 by 1/32 inch, is threaded around the pulleys. One end of the chain goes to the pen carriage above the drawing-board and over other pulleys to a weight of 300 grammes, which hangs below the table and serves to keep the chain under constant tension. The other end of the chain passes around two supplementary pulleys to another weight of 300 grammes which also hangs below the table. The chain is thus balanced and free to move through the entire series of 32 pulleys attached to the elements and over five other pulleys. These 37 pulleys are all made of aluminum and have ball-bearings. When the chain moves, it carries with it only the pen carriage and the two weights attached to its ends. The pen carriage rolls on ball-bearing wheels. The friction is so small that a pull of 120 grammes (about 4 ounces) is sufficient to move the chain and pen carriage. The small inertia of the wheels and the freedom from friction are important in allowing a small component movement of the elements of high order to be transmitted without loss through nearly the whole series of pulleys to the pen carriage. The design of the apparatus is such that each pulley, when in one extreme position, comes as close as possible to the centre line of the instrument; this gives the shortest possible length of chain, reducing the sag and stretch to a minimum. The chain is actually 27 feet long. Such a balanced chain is very convenient in setting the instrument, but the upper part of the chain must be held stationary in order that the various component motions of the

several pulleys may all be added and transmitted to the pen when a curve is being drawn. For this purpose a chain clamp *M*, Fig. 4, is provided; the clamp holds the chain to a rigid bar which passes under the various cross chains throughout the length of the machine. Many curves are drawn which have less than thirty components; to avoid the necessity of setting the higher elements, perhaps twenty or more in number, to zero for such curves, the chain clamp may be placed at any point where the chain crosses the centre bar. Then only those components which are between the clamp and the pen produce any effect on the motion of the pen; the components above the clamp may move in any degree, and they cause motion only in the upper part of the chain, which hangs freely with a weight on the end. If one wishes to draw a curve using only the upper components, as, for instance, components 29 and 30, the chain may be clamped just below element 29, and the upper end of the chain, instead of being attached to the weight below the table, is carried directly to the pen. Thus the threading of the long chain through the thirty pulleys which are not required is avoided. This adds to the delicacy of action. It is possible to draw a sine curve in this manner the actual amplitude of which is less than a hundredth of an inch, while so small a movement would hardly be passed around all the pulleys.

Most of the elements as shown in Fig. 4 are in medium or zero position, with the pins in the centres of the disks and with the radial slots of the disks parallel to the slots in the frame. So long as the pins remain in the central positions, rotation of the disks produces no motion of the frames and pulleys; when the pins are eccentric and the disks are rotated, the frames and pulleys are moved. The pins for four elements are shown at the extreme ends of the radial slots. The second disk in the lower row has been turned downward 90 degrees, which pulls the pen carriage upward on the drawing-board; one of the elements in the upper row is shown in a similar position. The third elements from either end of the lower row are shown with the disks rotated to the 270-degree position, which allows the pen to move downward over the board. As shown in the figure, the positions of the four displaced elements are such as to neutralize each other in pairs, and thus there will be no resultant displacement of the pen in this particular instance.

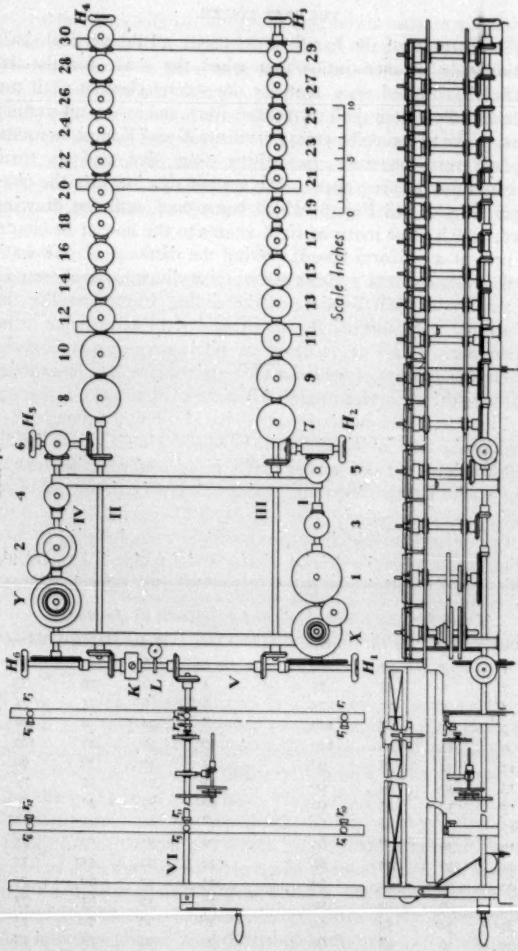

Scale Inches
0
5
10
Plan of the gear system of the synthesizer.

FIG. 7.

THE GEAR SYSTEM.

The turning of the handle must rotate all the vertical shafts continuously in such ratios that when the shaft for the first element has turned once, that for the second element shall turn twice and the others shall turn three, four, and so on, up to thirty times. The two supplementary elements *X* and *Y* must be rotated one half turn, one turn, two, three, four, five, and six turns, while number 1 turns once. The system also includes the phase dial *B*, Fig. 4 and Fig. 8, which turns once, and the drawing-board, which must move at right angles to the line of motion of the pen, at a uniform speed, moving the distance of one wave-length while element 1 turns once. The dimensions chosen for the amplitudes and the sizes of the sliding frames require that for compactness no gear for an element shall exceed five inches in diameter. Gears of 32 diametral pitch were chosen as giving convenient numbers of teeth for the required ratios. The vertical shafts are driven by four parallel horizontal shafts, *I*, *II*, *III*, and *IV*, Fig. 7. The four shafts are driven by one transverse shaft *V*, which in turn is driven by the handle shaft *VI*. The handle turns 30 times for one wave; shafts *V*, *II*, and *III* also turn 30 times, while *I* turns five times and *IV* turns six times per wave-length.

The following table shows the turns per wave-length (30 turns of the handle) for the driving shafts and for the disks, and also the number of teeth in the pairs of bevel gears for 30 elements:

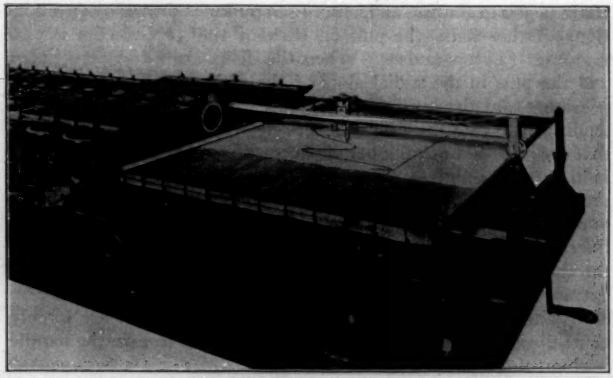
Turns for One Wave-length, or for 30 Turns of the Handle.

Disk	Shaft	Driver	Driven	Disk	Shaft	Driver	Driven
1	5	32	160	2	6	40	120
3	5	45	75	4	6	50	75
5	5	75	75	6	6	75	75
7	30	28	120	8	30	32	120
9	30	36	120	10	30	40	120
11	30	33	90	12	30	36	90
13	30	39	90	14	30	35	75
15	30	45	90	16	30	40	75
17	30	34	60	18	30	45	75
19	30	38	60	20	30	50	75
21	30	42	60	22	30	55	75
23	30	46	60	24	30	60	75
25	30	50	60	26	30	65	75
27	30	54	60	28	30	70	75
29	30	58	60	30	30	75	75

In certain kinds of work, the odd terms only in the Fourier series are required to represent a curve. In drawing such curves it is convenient to have only the odd-numbered elements of the synthesizer at work; for this purpose, a clutch *K*, Fig. 7, is provided in the transverse driving shaft *V* so that the shafts *II* and *IV* may be disconnected.

A pair of right-angle spiral gears *L*, Fig. 7, are connected to shaft *V* and, by means of a worm-gear of 30 teeth, turns the phase dial shown at the left of drawing-board, Fig. 8, and at

FIG. 8.



The drawing-board of the synthesizer.

B, Fig. 4. This dial indicates at all times the phase of the gear system as a unit independently of the phases of the separate elements, which are variable, and independent of the drawing-board, which is also adjustable. When setting up a curve, it is necessary that the gears be at zero phase, since only in this position are all the clamp screws of the cup-chucks *C*, Fig. 5, in position for the application of the clamp-wrench. This disk turns with the same speed as does the disk for the regular element No. 1, but it remains in a fixed relation to the gear system, while disk 1 may be set in various phases. The wave-length scale on the drawing-board also indicates phases, as is described later.

A pin stop is provided near the handle to hold the entire gear system fixed in zero position, while the several elements are being set in amplitude and phase. The handle itself is detachable by a bayonet catch. When verifying the settings of the amplitudes and phases of the elements, it is often convenient to be able to turn the gear system. For this purpose six hand-wheels, H_1, H_2, etc., Fig. 7, are connected to the driving shafts at points such that one can always easily reach one or two of the hand-wheels from any position near the machine.

A curious and interesting demonstration in statics is given by the system of gears, pulleys, and chains. The tension on the chain is 300 grammes, and, since each pulley is drawn by two portions of the chain, the pull on each of the 32 elements is 600 grammes (1⅓ pounds). When the disks are all at zero phase and the pins in the radial slots of the disks are all set as far as possible from the centres of the disks, they form 32 cranks, all tending to rotate the gear system one way. Actual trial shows that the pull on the crank handle necessary to lift the chain weight is about 23 pounds. At the same time that the chain pulls on the crank with 23 pounds pull, an additional weight of 4 ounces at one end of the chain will cause the chain to run freely through the entire series of pulleys and lift the weight on the other end of the chain. In actual practice, the crank pins are never all at the extreme eccentricity, and usually the phases of the cranks are so distributed that the crank actions on the gear system are largely neutralized. The pressure commonly required to turn the handle is about three pounds pull.

THE SUPPLEMENTARY ELEMENTS.

Thus 30 harmonic elements are provided, the amplitudes of the first five components being 100 millimetres each, and of the sixth, 90 millimetres. Two supplementary disks X and Y are provided, as already mentioned; disk X is driven by the vertical shaft of element 1 by means of a set of six change-gears with clutches; the disk Y is similarly driven by element 2. The gears for X permit it to be used for a component of frequency $1/2$,—that is, one octave below the fundamental (such a component is required for some musical tones), or for components 1, 2, 3, 4, or 5; the gears for Y give it frequencies corresponding to the components 1, 2, 3, 4, 5, or 6. Thus there is a sub-octave element

with an amplitude of 120 millimetres, and any one of the elements 1, 2, 3, 4, or 5 may have an amplitude of 340 millimetres, the other four being limited to amplitudes of 100 millimetres each at the same time; or any two of the elements 1, 2, 3, 4 or 5 may have amplitudes of 220 millimetres each, the other three being then limited to 100 millimetres each; element 6 may have an amplitude of 210 millimetres, and any one of the first five elements may at the same time have an amplitude of 220 millimetres, the other four not exceeding 100 millimetres each. The amplitudes for components 7 to 10 may be as large as 80 millimetres each, component 11 may have an amplitude of 60 millimetres, and components from 12 to 30 may have amplitudes of 50 millimetres each. The disks X and Y can be made to give any desired inharmonic components by providing for each a single gear of the required number of teeth.

While the drawing-board is only 24 inches wide and the curves being studied in musical analysis are rarely as wide as this, yet much wider curves can be drawn. By using a wide sheet of paper, the curve is drawn to the limit of the board, then the paper is shifted sidewise and the pen chain is loosened in its clamp and the pen is shifted to the new position of the trace, the chain is again clamped, and the drawing is continued. Any one of the first five components may be drawn with a width of 27 inches, and the maximum sum of all the components would make a curve more than 14 feet wide.

THE DRAWING-BOARD.

The chart table, Fig. 8, is an ordinary draughtsman's drawing-board, 24 by 34 inches in size, which is mounted in a very firm manner and at the same time it moves accurately in a straight line and with great ease. It is held firmly against its guides by springs so that there is no lost motion. Guards are provided so that when one end of the board overhangs the supports, pressure, such as leaning on the board, can not tip it up against the pen nor out of its guides; stops are provided which limit its extreme motions. The board is entirely supported on ball-bearing rollers arranged as shown in Figs. 7 and 8. Attached to the under side of the board are two tracks of cast bronze, which are machined and polished where they run on the rollers. The important requirement is that as the board moves from one extreme to the

other, about 32 inches, the pen, being stationary, shall trace a straight line on the surface of the board. This is secured by having the three rollers r_1, r_2, and r_3, Fig. 7, in a line, and by having the straight edge of the track always in contact with two (or sometimes three) of the rollers. The three rollers r_4, r_5, and r_6 are pushed against the second track by springs in their mountings with a pressure of about ten pounds, and thus they keep the first track firmly against its guide rollers. The weight of the board is supported by six (or four) ball-bearing rollers, r_7 to r_{12}. A pull of about one ounce will move the board.

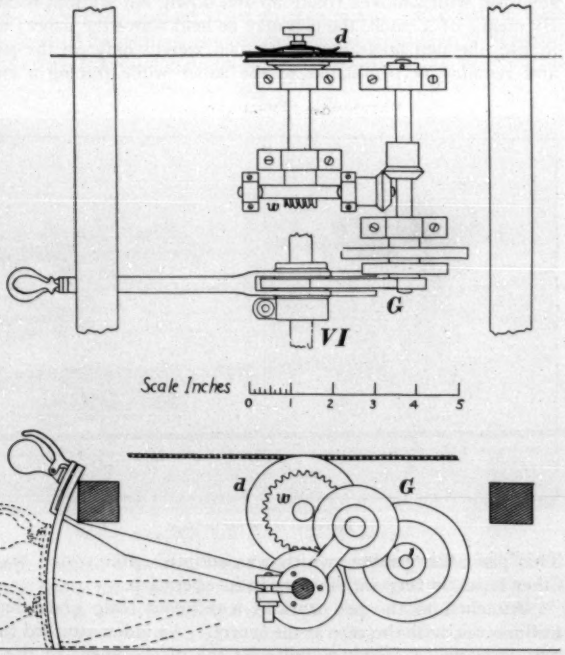
It is necessary that the board should travel exactly one wave-length when the handle is turned 30 times. The board is pulled by a chain, 1/10 inch wide and 1/20 inch thick, which winds around a metal drum *d*, Fig. 9, of such a size that one revolution moves the board 200 millimetres. The drum is turned by a worm-gear *w*, of 30 teeth, and the worm is driven from the handle shaft *VI*, Figs. 7 and 9, by means of the change-gear system *G*. The change gears are arranged for wave-lengths of 133.3 millimetres, 200 millimetres, and 400 millimetres. Any desired wave-length can be easily provided by substituting a gear of suitable size in the change-gear system, or by using a drum of proper diameter.

The drum around which the chain passes is held on its driving shaft by friction only. The friction is sufficient for moving the board properly from the driving gear. But it is possible, by exerting a little extra pressure on the board, to move it by the slipping of the drum on its friction holder, and so to set the board at any time to any phase position, independently of the handle and the gear system. This is a very great convenience, since after a curve has been traced by turning the handle forward, 30 turns for each wave-length, the board can be instantly pushed to the starting point for a new tracing instead of having to turn the handle backward the 30 or more turns. With any particular phase of the gear system, one can instantly bring any part of the drawing-board under the pen; it is, in effect, an endless drawing-board. The length of the curve drawn is usually one or two wave-lengths of about 16 inches each, but by shifting the paper on the board a curve of any length may be drawn.

On one edge of the drawing-board is a linear scale, Fig. 8, which shows the travel of the board in terms of the wave-length

of the curve being drawn, or it shows the phase of that part of the curve being traced. Since the drawing-board is held by friction only, this scale enables one to set the board in phase with the gear system as indicated by the dial adjacent to the scale.

FIG. 9.



Plan of gears for moving the drawing-board.

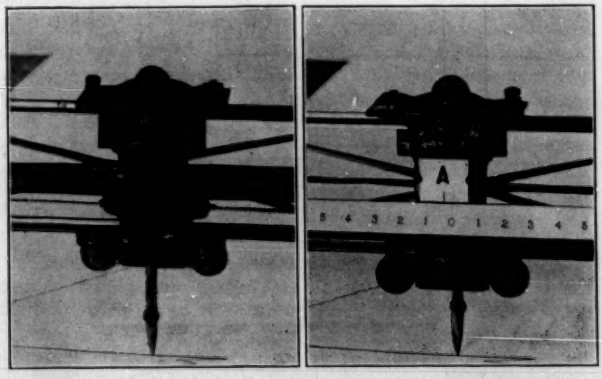
THE DRAWING PEN.

The pen track is a truss of cast bronze with six planed and polished ways. The pen carriage rolls on eight ball-bearing wheels. Five of these rollers are fixed to the carriage, while the other three hold the carriage firmly against the track by spring pressure exerted in three directions so that there is no lost motion.

While the carriage is held tightly to the track, yet it moves with great ease, a pull of about one ounce being sufficient to roll it along. Views of the two faces of the carriage are shown in Fig. 10.

The pen is an ordinary draughtsman's ruling pen, held in a steel rod which moves freely up and down, but without rotation. By means of a catch, the pen may be held above the paper; when in use, the pen presses with its own weight only on the paper, and remains perpendicular to the paper while tracing a curve.

FIG. 10.



Two views of the pen carriage.

This pen arrangement, which was adopted after trying several other types, is very satisfactory in its operation.

Attached to the pen track is a celluloid scale graduated in millimetres, with the zero at the centre. An index attached to the pen carriage, *A*, Fig. 10, indicates the displacement of the pen along the track; that is, it shows the amplitude of the curve at each instant.

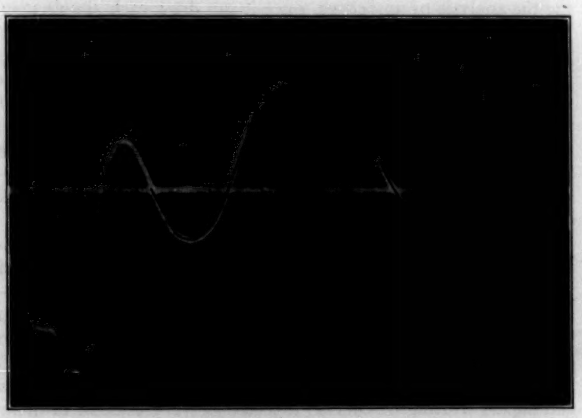
APPLICATIONS OF THE SYNTHESIZER.

In order to set the synthesizer for drawing a given curve, it is necessary to know the amplitude and the phase of each component; these quantities are the coefficients and epochs in the Fourier equation of the curve when the equation is given in the

form of a single series of sines or cosines. If the equation is given in the form of the double series of sines and cosines, it must be reduced to the single series. A machine for assisting in this reduction will be described in a later paper in this journal.

The handle of the machine is turned till the gear system is in zero phase, and it is then locked. The disk for each element up to the highest to be used is set to zero phase. The pin on each disk is set to the right of the centre to the amplitude in millimetres of the corresponding component, as indicated by the scale on the

FIG. 11.



Proof of the analysis of a curve by synthesis.

frame. Each disk is rotated in its cup-chuck till the divided circle reads the phase for the corresponding component. The pen chain is adjusted till the pen is on the desired axis, and it is clamped just above the highest element being used. The drawing-board is adjusted to the zero phase position. Then 30 turns of the handle will cause the pen to trace one complete wave of the desired curve. A ten-component curve can be synthesized in about five minutes, while the machine may be set for 30 components and the curve be drawn in 12 minutes.

In the study of sound waves, the synthesizer is chiefly used to verify the correctness and sufficiency of the analyses. The

several elements of the machine having been set to reproduce the separate components in exact sizes and phases, as determined with the analyzer, the tracer will draw the resultant curve. If this resultant is exactly like the original curve which was analyzed, the analysis is correct and complete, and the fact is recorded by tracing the synthetic curve over the original in a contrasting color of ink. Fig. 11 shows the synthetic reproduction of the analysis of an organ-pipe curve drawn by machine on an enlarged photograph of the original.

The harmonic synthesizer is useful for graphically interpreting the analysis of any curve, since it can draw each simple component in its proper size and position as well as the resultant of all the components. The details of such an analysis have been explained elsewhere by the writer.[10] The complex curve at the top of Fig. 12 represents the sound wave from a clarinet. The analysis of this curve showed the presence of 20 components, and the synthesizer was set to reproduce them; the composite is drawn in the upper part of the figure, while each component is shown separately below. These curves are reproduced directly from ink drawings made by the machine.

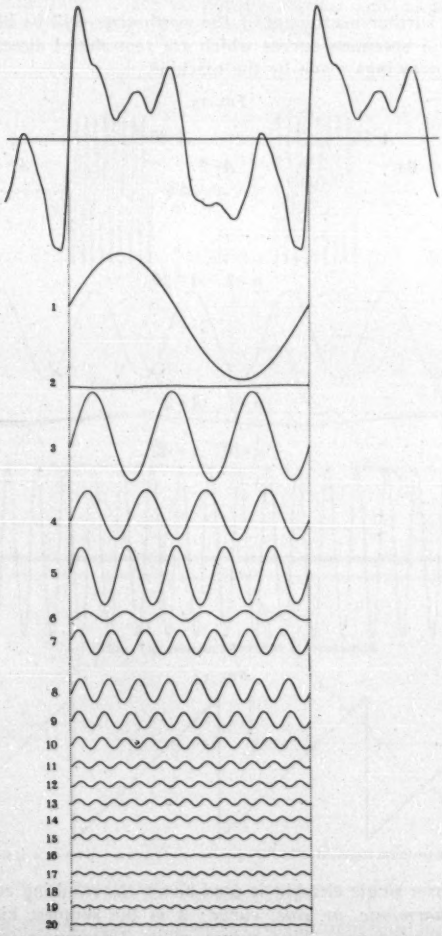
The synthesizer is also used for drawing a curve corresponding to the average of several curves, and for drawing curves of any assumed composition, as in trial analysis. After a photographed curve has been analyzed and the components have been corrected for instrumental disturbances, it is often desired to draw the corrected synthetic curve.

The synthesizer is useful in preparing illustrations for books and papers treating of curves; it would be very difficult to draw the curves of correct form by any other means.

When the synthesizer is set for any curve, if the handle is turned till the phase circle for the first component reads 0°, the circles for the other components show, without calculation, the relative phases, or, as sometimes called, the epochs, of the several components; the tracing point will now be at what may be considered the initial point of the wave, though in general this will not be where the curve crosses the axis.

The mathematician finds the harmonic synthesizer helpful in the investigation of many kinds of curves, and the properties of periodic functions and the convergency of series can be shown graphically.

FIG. 12.

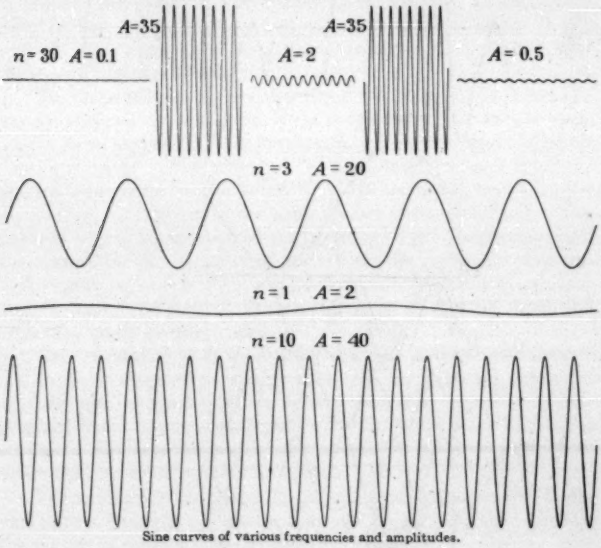


A curve representing the sound wave from a clarinet and its harmonic components.

THE STUDY OF CURVES WITH THE SYNTHESIZER.

The further usefulness of the synthesizer will be illustrated by several specimen curves which are reproduced directly from the ink drawings made by the machine.

FIG. 13.



Sine curves of various frequencies and amplitudes.

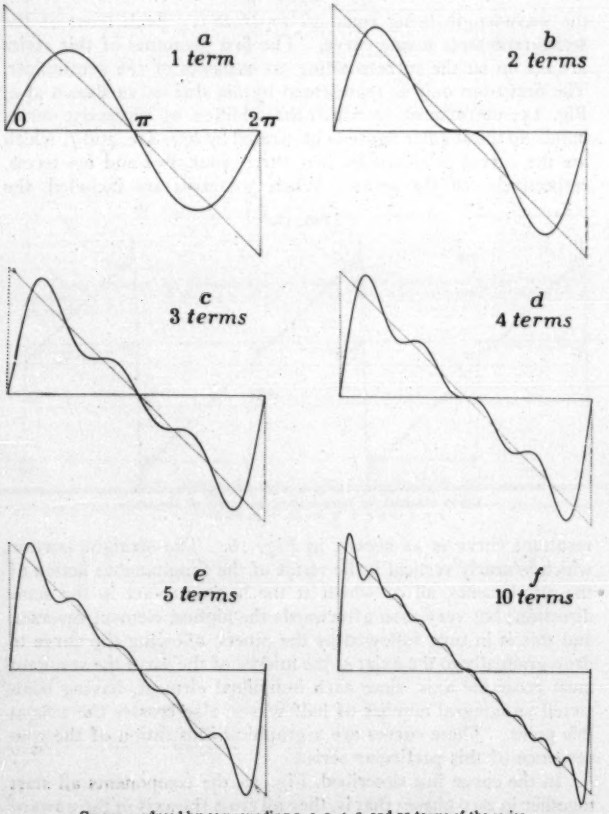
FIG. 14.

An angular wave-form represented by the equation: $y = 2(\sin x + \frac{1}{3}\sin 2x + \frac{1}{5}\sin 3x + \ldots)$.

When a single element is used alone, the resulting curve is a *simple harmonic,* or *sine, curve;* it is the simplest kind of a smooth wave-form. Sine curves, while differing in frequency,

n, and amplitude, A, are all equally regular and simple. All the curves shown in Fig. 13 are sine curves.

FIG. 15.



Curves produced by compounding 1, 2, 3, 4, 5, and 10 terms of the series $y = 2(\sin x + \frac{1}{2}\sin 2x + \frac{1}{3}\sin 3x + \ldots)$.

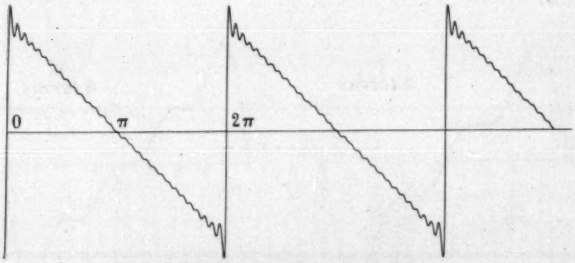
A geometrical figure composed of two straight lines inclined at an angle of 45 degrees, when repeated, produces the angular wave

shown in Fig. 14. The Fourier equation of this curve is an infinite series of the form,

$$y = 2(\sin x + 1/2 \sin 2x + 1/3 \sin 3x + 1/4 \sin 4x + \ldots),$$

the wave-length being equal to $2\pi = 6.28+$. Each term of the series represents a sine curve. The first 30 terms of this series are set up on the corresponding 30 elements of the synthesizer. The first term only is represented by the sine curve shown at *a*, Fig. 15; the manner in which the addition of successive terms builds up the angular figure is illustrated by *b*, *c*, *d*, *e*, and *f*, which are the curves produced by two, three, four, five and ten terms, respectively, of the series. When 30 terms are included, the

FIG. 16.

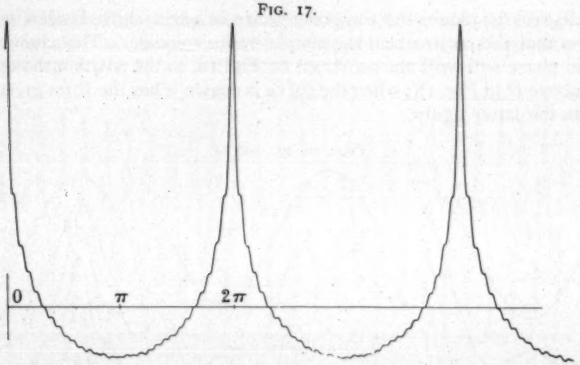


Curve obtained by compounding 30 terms of the series
$y = 2 (\sin x + \frac{1}{2} \sin 2x + \frac{1}{3} \sin 3x + \ldots)$.

resultant curve is as shown in Fig. 16. The straight portion which is nearly vertical is the result of the simultaneous action of the 30 elements, all of which at the beginning act in the same direction; but very soon afterwards the highest element reverses, and this is in turn followed by the others, allowing the curve to drop gradually to the axis; at the middle of the wave the resultant must cross the axis, since each individual element, having completed an integral number of half waves, also crosses the axis at this point. These curves are a graphical illustration of the convergence of this particular series.

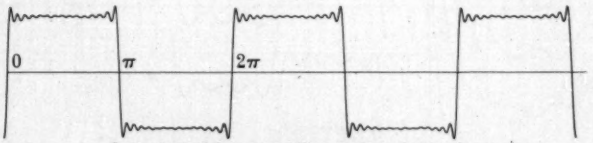
In the curve just described, Fig. 16, the components all start together in zero phase; that is, they all cross the axis in the upward direction at the same point, the middle of the vertical line. When the synthesizer is in this zero position, if each disk is turned 90

FIG. 17.



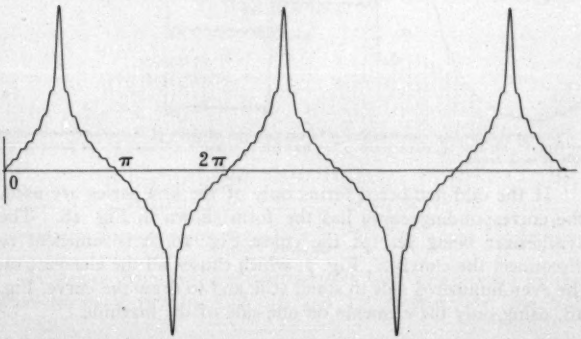
Curve obtained by compounding 30 terms of the series $y = 2\ [\sin (x + 90°) + \frac{1}{3} \sin (2x + 90°) + \frac{1}{5} \sin (3x + 90°) + \ldots]$, which is equivalent to $y = 2\ (\cos x + \frac{1}{3} \cos 2x + \frac{1}{5} \cos 3x + \ldots)$.

FIG. 18.



Curve obtained by compounding 15 terms of the series $y = 2\ (\sin x + \frac{1}{3} \sin 3x + 1/5 \sin 5x + \ldots)$.

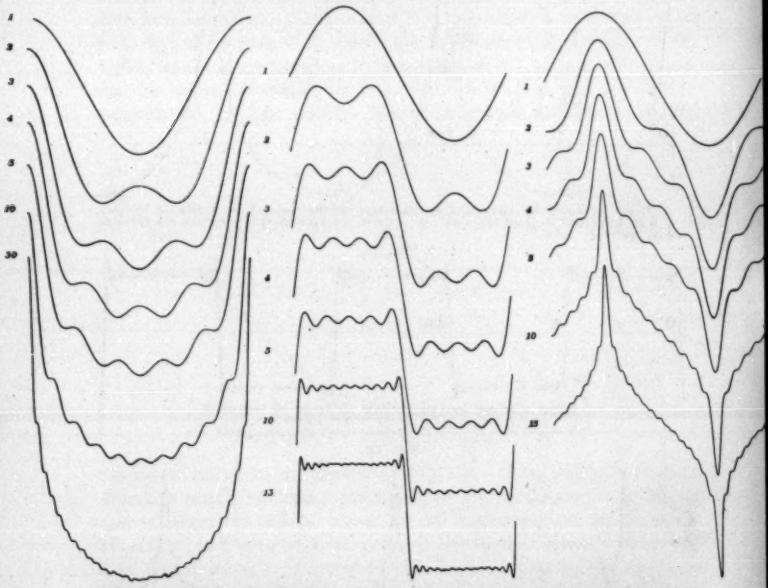
FIG. 19.



Curve obtained by compounding 15 terms of the series $y = 2\ [\sin x + \frac{1}{3} \sin (3x + 180°) + 1/5 \sin 5x + 1/7 \sin (7x + 180°) + \ldots]$, which is equivalent to $y = 2\ (\sin x - \frac{1}{3} \sin 3x + 1/5 \sin 5x - 1/7 \sin 7x + \ldots)$.

degrees in phase, the components are in effect shifted sidewise, so that the *crests* of all the simple waves coincide. This change in phase will shift the pen from *O*, Fig. 16, to the position shown above *O* in Fig. 17; when the curve is drawn it has the form given in the latter figure.

FIGS. 20, 21, and 22.



Curves obtained by compounding different numbers of terms of the series corresponding to Figs. 17, 18, and 19, respectively. The number of terms is indicated by the figure at the side of each curve.

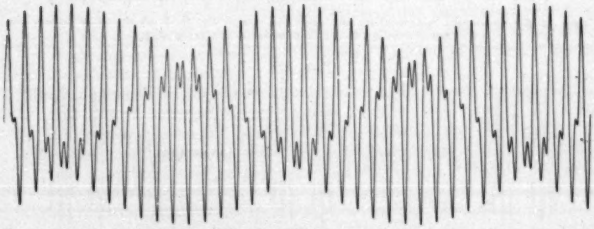
If the odd-numbered terms only of the first series are used, the corresponding curve has the form shown in Fig. 18. The synthesizer being set for the curve Fig. 16, it is sufficient to disconnect the clutch *K*, Fig. 7, which causes all the elements on the even-numbered side to stand still, and to draw the curve, Fig. 18, using only the elements on one side of the machine.

With the same components as for Fig. 18, but with the phases of the alternate terms shifted 180 degrees, a further interesting variation in the curve is obtained, as shown in Fig. 19.

FIG. 23.

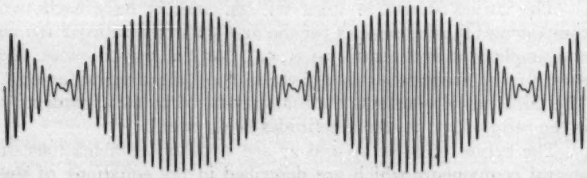
Curve of two components representing the equation $y = 40 \sin 10x + 25 \sin 29x$, the wavelength being 133.3.

FIG. 24.



Curve of two components representing the equation $y = 40 \sin 15x + 25 \sin 29x$, the wavelength being 133.3.

FIG. 25.



Curve of two components corresponding to beats. $y = 25 \sin 29x + 25 \sin 30x$, the wavelength being 133.3.

If sounds from two different sources were represented by the wave-forms shown in Figs. 16 and 17, respectively, the two

sounds would be of exactly the same loudness and of the *same tone quality*, according to the accepted theory, since they are composed of exactly the same components or partial tones, which differ only in phase. The same remark applies to the two curves shown in Figs. 18 and 19. These illustrations show that the interpretation of the records of complex phenomena requires careful analysis.

The building up of the curves, Figs. 17, 18, and 19, is illustrated by Figs. 20, 21, and 22; the number of components entering into each curve is indicated by the figure at its side.

FIG. 26.

Curve of 8 components representing the equation $y = 20 \sin 3x + 16 \sin 9x + 12 \sin 15x + 8 \sin 21x + 4 \sin 27x$, the wave-length being 133.3.

FIG. 27.

Curve of 8 components representing the equation $y = 10 \sin 26x + 8 \sin 27x + 6 \sin 28x + 4 \sin 29x + 2 \sin 30x - 10 \sin 24x - 8 \sin 23x - 6 \sin 22x - 4 \sin 21x - 2 \sin 20x$, the wave-length being 133.3.

The curves shown in Figs. 23, 24, and 25 have each two components; the frequencies for the first are in the ratio of 10:29 and amplitudes in the ratio of 8:5. For the second curve, the ratio of the frequencies is 15:29, and of the amplitudes 8:5. The third curve represents the beats produced by two frequencies in the ratio of 29:30, the amplitudes being equal.

The curves of Figs. 26 and 27 are arbitrary combinations of several components which are described in the equations of the legends; these are interesting only as showing beauty of form. The number of curious curves which can be drawn is indefinite; various other forms have been desceribed by Donkin and by Michelson.[8, 9]

REFERENCES.

[1] Fourier's Series: J. B. J. Fourier, "La Théorie Analytique de la Chaleur," Paris (1822), and "The Analytical Theory of Heat," English translation by Alexander Freeman, Cambridge (1878), 466 pages; W. E. Byerly, "Fourier's Series and Spherical Harmonics," Boston (1893); H. S. Carslaw, "Fourier's Series and Integrals," London (1906); C. P. Steinmetz, "Engineering Mathematics," 2d ed., New York (1915), pp. 94–146; Carse and Shearer, "Fourier's Analysis and Periodogram Analysis," London (1915), 66 pages.

[2] Harmonic Analyzer: Lord Kelvin, *Proc. Royal Society*, **27**, 371 (1878); Kelvin and Tait, "Natural Philosophy," Cambridge (1896), Part 1, Appendix B [2], vii, pp. 505–508.

[3] Sphere-and-cylinder Integrator: James Thomson, *Proc. Royal Society*, **24**, 262 (1876); Kelvin and Tait, "Natural Philosophy," Cambridge (1896), Part 1, Appendix B [3], iii, pp. 488–492.

[4] Various Harmonic Analyzers: Carse and Urquhart, Horsburgh's "Modern Instruments of Calculation," London (1914), pp. 220–253, 337; H. de Morin, "Les Appariels d'Intégration," Paris (1913), pp. 147–188; G. U. Yule, *Philosophical Magazine*, **39**, 367–374 (1895); J. N. LeConte, *Physical Review*, **7**, 27–34 (1898); T. Terada, *Zeitschrift für Instrumentenkunde*, **25**, 285–289 (1905). Henrici's Harmonic Analyzer: O. Henrici, *Philosophical Magazine*, **38**, 110 (1894); D. C. Miller, "Science of Musical Sounds," New York (1916), p. 97.

[5] Graphic Composition of Harmonic Motions: F. Bashforth, *British Association Report*, Transactions of Sections, pp. 3 and 4 (1845); J. D. Everett, "Vibratory Motion and Sound," London (1882), p. 90.

[6] Tide Predictor: Kelvin and Tait, "Natural Philosophy," Cambridge (1896), Part 1, Appendix B [1], i, pp. 479–482; Lord Kelvin, "Popular Lectures," vol. iii, p. 184.

[7] Tide-predicting Machine: E. G. Fisher, *Engineering News*, **66**, 69–73 (1911); *Special Publication* No. 32, United States Coast and Geodetic Survey, Washington (1915), 35 pages.

[8] Harmonic Analyzer and Synthesizer: Michelson and Stratton, *American Journal of Science*, **5**, 1–13 (1898); *Philosophical Magazine*, **45**, 85 (1898). A. A. Michelson, "Light Waves and Their Uses," Chicago (1903), p. 68.

[9] Various Harmonic Synthesizers: W. G. Cady, *Physical Review*, **22**, 249 (1906); W. F. Donkin, *Proc. Royal Society*, No. 150 (1874), and "Acoustics," Oxford (1884), p. 50; J. D. Everett, Donkin's Harmonograph, "Vibratory Motion and Sound," London (1896), p. 85; Horsburgh, "Modern Instruments of Calculation," London (1914), pp. 337–339.

[10] Harmonic Analyzers and Synthesizers, general description, with illustrations: D. C. Miller, "Science of Musical Sounds," New York (1916), pp. 92–141.

Animals and Plants Which Live in Brines and Raw Salt. (*Overland Guidebook*, Bulletin No. 612, U. S. Geological Survey.)—Just west of Promontory Point station, Utah, is a pond cut off from the Great Salt Lake by the railroad embankment. At times of high water in the lake this reservoir fills by percolation through the embankment, but during the summer this water is concentrated to a brine by evaporation. The deep-pink color of the brine is a phenomenon that appears in salt ponds generally when a certain concentration is reached. In the salt ponds of San Francisco Bay this color is due to a certain bacillus which lives in saturated brines and also in the heaps of salt as it is piled for drainage and shipment. Prohibitive to life as such an environment might be considered, strong natural brines are, in fact, inhabited by a number of minute organisms—animals as well as plants. The pink color disappears in winter or when fresh water is introduced into the pond. The Southern Pacific Company has done some experimental work on preserving piles and railroad ties by soaking them in the pond.

The Production of Acetone from Pyroligneous Acid. M. DARRIN. (*The Journal of Industrial and Engineering Chemistry*, vol. 7, No. 11, November, 1913.)—The purpose of the work reported in this paper is to show the yield of acetone that can be obtained from pyroligneous acid by means of a continuously-operated electric furnace, containing a catalyzer, which converts the acid directly into acetone without necessitating the intermediate production of the acetate.

The raw material consisted of pyroligneous acid obtained by the destructive distillation of Douglas fir mill waste at the half-cord wood distillation plant designed by the author and erected coöperatively by the University of Washington and the United States Forest Service. Before treatment the pyroligneous acid was distilled in order to separate and recover the turpentine, oils, tar, alcohol, etc., since it was thought these substances might have an injurious effect on the catalyzer, and since these by-products are necessarily separated and recovered in commercial practice up to the point where the redistilled acid is neutralized with milk of lime for the manufacture of the gray acetate. At this stage the present practice is to mix the pyroligneous acid with the lime in large tanks until neutralization is complete, as shown by the color change. The principal acid constituent of pyroligneous acid is acetic acid. It is then evaporated to a pasty consistency, dried, and shipped away as "gray acetate of lime" to the acetone plant, where it is destructively distilled in steel retorts, breaking down into acetone and calcium carbonate. The acetone is condensed, washed, and refined in a column distillation apparatus. Among other advantages over the ordinary methods of making acetone from the acetate are higher yields in acetone, lower cost of apparatus and operation, and easy and automatic control assuring uniform results.

RECENT PROGRESS IN THE METALLURGY OF COPPER.*

BY

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I. INTRODUCTION.

THE aim of all smelting of sulphide copper ore is to collect the copper in matte which contains usually 40 to 45 per cent. Cu, 35 to 30 per cent. Fe, and 25 per cent. S, and the missing constituents in a slag, a mixture of silicates of iron, lime, etc., low enough in Cu to form a waste product. The iron and sulphur of the matte are separated from the copper by the converter process. This furnishes a crude copper and slag which is too rich in copper to be discarded, and goes back into the ore-smelting; the crude copper is subjected to a fire-refining operation which gives it the mechanical properties demanded by the metal industries.

In the treatment of my subject I intend to cover the progress which has been made mainly during the last ten years in

1. The smelting of sulphide copper ore in the blast furnace.
2. The smelting of sulphide copper ore in the reverberatory furnace.
3. The conversion of copper matte into crude metallic copper.
4. The fire-refining of crude copper to the market product.

II. SMELTING SULPHIDE COPPER ORE IN THE BLAST FURNACE.

For a great many years all smelteries used the roasting and reduction process. In our days the process is found, on this continent at least, only in a few instances, and the two leading representatives are the Canadian Copper Company and the Mond Nickel Company, near Sudbury, Ontario. As the name of the process indicates, we have to deal with two separate operations.

The first is roasting. This aims to eliminate, by oxidation, all the sulphur in excess of that which is required to furnish the 25 per cent. necessary for the matte to be formed in smelting,

* Presented at the stated meeting of the Institute held Wednesday, October 20, 1915.

and to oxidize part of the iron, that it may enter the slag. A blast furnace requires, for good work, coarse ore. The lump ore from the mine which is to be roasted is therefore only broken to pass a 3-inch ring, and the coarse product then roasted in heaps. A heap is a truncated pyramid of ore not larger than 3 inches in diameter, built onto a bed of wood and covered more or less with fine ore to check the draft. The wood is ignited, kindles the overlying ore, and this burns with a smouldering fire, for weeks or months, the oxidation of the sulphur and iron furnishing the necessary heat. The Canadian Copper Company has heaps 55 by 100 feet and 10 to 12 feet high, holding 1000 tons of ore with 20 per cent. S, 40 per cent. Fe, 5 per cent. CuNi, and 24 per cent. gangue. A roast lasts from 10 to 12 weeks; the roasted ore retains 10 to 12 per cent. S.

The second step is smelting. It aims at reduction and fusion. The ore is charged with coke and some flux into a blast furnace; it is subjected to increasing temperatures as it descends in the furnace, and to the two reducing agents C and CO. The result is that all oxidized copper is reduced and sulphurized, and with it a varying amount of iron; the two sulphides then form the matte. The remaining oxidized iron of the ore is reduced to the ferrous state and combines with the silica of the ore to a ferrous silicate. Other oxides, such as calcium oxide, alumina, etc., also form silicates, and the combined silicates give the waste slags. This formation of copper matte is made possible by the strong affinity copper and iron have for sulphur. So long as there is sulphur in the charge the copper will combine with it to form Cu_2S and the sulphur still present will be available to form FeS. The difference in specific gravity of matte and slag, 5.5 and 3.5, allows a good separation so long as the temperature in the earth is high enough to keep matte and slag thoroughly fluid, and a removal from different levels of the hearth.

This roasting and reduction process is expensive and slow, and has had to yield to what is called the pyritic process. This is a blast-furnace process in which the oxidation of raw pyritic ore furnishes all the heat necessary to carry on the operation. An ore to be suited for the process must consist mainly of pyrite or pyrrhotite and uncombined silica. As such ores are scarce, pure pyritic smelting is not common, and partial pyritic smelting has taken its place. In this process the lack of heat caused by the

unfavorable composition of the ore is made up by the combustion of coke added to the charge.

Pyritic furnaces have been run for days at a time without any carbonaceous fuel whatever; usually, however, 2 to 3 per cent. coke is added to the charge, the carbon of which is oxidized by the sulphur dioxide in the ascending gases near the throat of the furnace and thus warms the charge. In partial pyritic smelting 6 or more per cent. coke is added to the charge, and this coke is burnt by the blast entering at the tuyères. The chemical distinction between pure and partial pyritic smelting lies in the oxidation of the coke; if all of it is oxidized by the sulphur dioxide of the ascending gases near the throat, we have pyritic smelting; if all or most of it is oxidized by the blast, we have partial pyritic smelting.

The chemical analyses of the blast-furnace gases bring out clearly the difference. Gases from pyritic smelting contain SO_2 6 to 8, CO_2 5 to 16, CO none, free O none or less than 0.8 per cent. vol.; gases from partial pyritic smelting contain SO_2 2, CO_2 up to 14, CO none to 2, free O 8 to 10 per cent. vol.

The tuyère region of the furnace with pyritic smelting is cool; that with partial work is hot.

The sides of the pyritic furnace become covered above the tuyère region with a bosh consisting of siliceous material of the charge, and this is not the case with partial work.

The slag of pyritic work is usually a singulo-silicate; that of the partial process is much more siliceous.

The best exponent of the pure pyritic process is found in the work done by Sticht at Mount Lyell, Tasmania. The blast furnace, 54 by 210 inches at tuyères and 23 feet 7 inches high, with 24 oblong tuyères, 15 by 3.5 inches, puts through in 24 hours 400 to 500 tons charge containing 2.5 per cent. Cu, 25 to 30 per cent. S, and 3 per cent. coke, with 18,000 cubic feet blast per minute, at a pressure of 64 ounces per square inch. It produces matte with Cu 45 to 52 per cent., and slag with SiO_2 35 to 38, FeO 40 to 48, Ca(Mg)O 3.0 to 3.5, BaO 2.0 to 3.0, Al_2O_3 0.5 to 8.3, and Cu 0.3 to 0.4 per cent. Thus 95 to 97 per cent. of the sulphur is burnt off and a matte with Cu 45 to 52 per cent. produced from ore with Cu 2.5 per cent., which corresponds to a concentration of 50 into 1.

Partial pyritic smelting is the process used almost universally

in this country and has been brought to a high degree of perfection.

At Great Falls, Mont., the modern copper blast furnace has been evolved by Klepetko. It has been changed in some details, here and there, to meet local requirements, but the original typical form has been retained and has made its way around the world. The furnace, 56 by 180 inches at tuyères and 14 feet 10 inches high, with 26 tuyères 3 inches in diameter, puts through in 24 hours 350 tons charge containing 6.89 per cent. Cu, 14.7 per cent. S, and 10 per cent. coke, with 10,500 cubic feet air per minute, at a pressure of 40 ounces per square inch. It produces matte with 50 per cent. Cu and slag with SiO_2 37.7, FeO 26.2, CaO 24.4, Al_2O_3 8.0, and Cu 0.32 per cent. Thus 78 per cent. of the sulphur is burnt off, and a concentration affected of 7 into 1.

The striking economic features of the two records are the smelting power (Mount Lyell, 6.8 tons per square foot hearth area in 24 hours, against 5 of Great Falls), and the concentration of ore into matte (Mount Lyell, 50:1, against Great Falls, 7:1). They bring out the favorable character of the ore of Mount Lyell in comparison with the refractory nature of the material treated at Great Falls.

At Anaconda, Mathewson, in 1905, joined two neighboring furnaces, 180 inches or 15 feet long, by removing the facing end-walls and filling in the 21-foot space with a new furnace; he thus obtained a hearth $15 + 15 + 21 = 51$ feet long. This worked so satisfactorily that when another remodelling became necessary in 1906 he erected a furnace 87 feet in length, retaining the standard Great Falls width at tuyères of 56 inches. This monster furnace, 56 by 1044 inches at tuyères and 13 feet 4 inches high, with 150 tuyères 4 inches in diameter, puts through in 24 hours 1400 tons charge (or 5.88 tons per square foot hearth area), containing 6.79 per cent. Cu and 13.80 per cent. S and 8.70 per cent. coke, with 52,070 cubic feet air per minute, at a pressure of 40 ounces per square inch. It produces matte with 43 per cent. Cu and slag with SiO_2 39.3, FeO 24.2, CaO 25.2, Al_2O_3 6.2, and Cu 0.3 per cent. There is burnt off 70.58 per cent. of the sulphur, and the concentration is 6.3 into 1. The advantages accruing from such a large furnace lie in the saving of labor and of fuel, and in the improvement of the smelting as a whole.

Very few smelteries have enough ore to treat to permit following the example of Anaconda; large-size furnaces erected at

present are 20 to 30 feet long inside at the tuyère-level; the width ranges from 44 to 56 inches, depending upon the coarseness of the ore. The working height ranges from 13 to 16 feet.

With such large furnaces the preparation of charge, the removal of matte and slag, the supply of air necessary to burn the coke and sulphur, and the recovery and handling of flue dust have shown great improvements over older devices.

In a modern plant the components of the charge are collected in hopper-shaped bins provided with gates and weighing devices and trains of side-discharge cars travelling beneath. These receive the required amounts of ore, flux, and coke, are hauled to the feed-floor on tracks running along the sides of the furnaces, and their contents dumped on one side and then on the other onto deeply inclined cast-iron plates extending from the feed-floor into the furnace. The desired distribution of the furnace materials is attained by allowing the surface of the charge in the furnace to sink more or less before new material is introduced. In this way the ore, flux, and fuel falling from the dumping cars can be delivered near the side or the centre of the furnace.

At the works of the Cananea Consolidated Copper Company, the Tennessee Copper Company, and the Calumet and Arizona Copper Company the Dwight-Messiter ore bedding system has been introduced by means of which ores for the blast or reverberatory furnaces are sampled, bedded, reclaimed, and delivered mechanically to the furnace bins at a cost of 9 cents per ton.

With most furnaces the melted matte and slag flow together from the furnace beneath a tymp, which traps the blast, into a fore-hearth, usually 14 feet in diameter and 5 feet high, in which the matte separates from the slag. The matte is tapped periodically into ladles which go to the converting department, while the slag overflows continuously either into slag cars to be hauled to the dump, or is granulated by a stream of pressure-water which carries away the granules.

The blast is supplied in most cases by Roots or Connersville rotary pressure blowers. In recent years the turbo-blower is gaining favor, as it delivers a definite amount of air irrespective of the pressure prevailing in the furnace. This is not the case with the rotary pressure blowers.

The gases issuing from the open throat of a blast furnace are cool, 150° to 250° C. in a reducing fusion and in true pyritic smelt-

ing; they are hot in partial pyritic work, 300° C. and over. With a speed of about 750 feet per minute they carry along with them dust and volatile components of the charge. Most of the dust is readily collected if the gases are sufficiently cooled and their speed retarded to 150 feet per minute. The remaining dust and most of the volatile materials used to pass off into the open. Three methods of collecting them have proved economically successful: the Roesing wire system at Great Falls, Mont.; bag-filtration at the Mammoth smelter, Shasta, Cal.; the Cottrell system of electric condensation is being tried out at Anaconda, Mont., on a large scale.

In the Roesing system, steel wires are suspended in the chamber through which pass the gases. The friction caused between the travelling gases and the stationary wires causes a retardation of the velocity, and with it a settling of the suspended particles. At Great Falls, Mont., Nos. 6 and 8 gauge wires form a horizontal screen, with openings $\frac{5}{8}$ inch square, from which are suspended No. 10 gauge wires 16 and 20 feet long. The chamber holds 1,200,000 wires. It is 348 feet long, 176 feet wide, and 21 feet high. From the entrance to the chamber, for a distance of 150 feet, and back from the exit, also for 150 feet, the space is wired; the intervening space is left free from wires. The purpose of this arrangement is to collect dust in the entrance division and fume in the exit division. The arrangement has proved a complete success. The wire system is shaken mechanically from the outside for 30 minutes at intervals of 60 to 90 days to dislodge the adhering dust and fume; this collects in the hoppers of the floor and is gathered.

At the Mammoth smelter, Shasta, Cal., the gases from the blast furnaces are cooled to 100° C. by drawing with a fan through a series of air-cooled soft-steel pipes, admitting at the same time some air, and then forcing them through a bag-house which contains 3000 suspended woollen bags 34 feet long and 18 inches in diameter. These filter the gases and hold back all solid matter. Furnace gases from pyritic smelting contain SO_2 and SO_3. The corroding effect of SO_3 is neutralized by the Sprague process, in which zinc oxide produced from blende on a Wetherill grate is fed into the gas current; this oxide unites with uncombined SO_3 and forms harmless $ZnSO_4$.

The Cottrell process aims to collect dust and fume by having

a high-potential direct current jump through the cooled gases travelling in the flue, from the needle-points of one pole to the plate-poles of the other. This causes particles of dust and vapor to travel toward the plates with a speed which is proportional to the charges and to the potential gradient between point and plate. This process has proved very effective at Garfield, Utah, for cleaning converter gases. The large-scale experimental work carried on at Anaconda, Mont., is very promising.

The handling of flue dust has shown many improvements.

Briquetting, the old standard method, is falling into disuse. The Tennessee Copper Company pours matte from a ladle over a bed of flue dust. The matte takes up the dust, and the dust furnishes part of the siliceous addition necessary for converting. The Cananea Consolidated Copper Company pours flue dust and liquid converter slag together into a slag-bowl, and this, when filled, is emptied over an inclined slag-dump, where the contents passing downward form lumps suitable for blast-furnace work. The Copper Queen Smeltery, Douglas, Ariz., feeds flue dust and liquid converter slag into a revolving conical cast-iron drum, and discharges the two, intimately mixed, in the form of balls. The Mason Valley Mines Company, near Wabuska, Nev., has in operation two 100-ton Dwight-Lloyd sintering machines in which flue dust with fine sulphides and some coke-fines are blast-roasted to hard cellular cakes.

III. SMELTING SULPHIDE ORE IN THE REVERBERATORY FURNACE.

Until about twenty years ago most sulphide copper ores were smelted in the blast furnace; about ten years ago reverberatory-furnace smelting became quite important; the great improvements made within the past two or three years have made the reverberatory furnace so prominent that, *e.g.*, Anaconda has given up its blast furnaces.

We have seen that the blast furnace requires lump ore if it is to do good work. This lump ore must run high in copper if the operation is to be profitable; but high-grade ores are not abundant, hence the prevailing medium and low-grade ores have to be enriched by ore-dressing work. The enriched product, the concentrate, is a fine-sized material, which is exactly what the reverberatory furnace requires for good work. The losses of copper mineral in ore dressing have been large. The recent advances made

by flotation methods to treat the slimes produced in ore-dressing have been so successful that the loss in copper mineral has been greatly reduced. There is therefore less hesitation than formerly to enrich ores suited for blast-furnace work by ore-dressing work, and to smelt the entire product of the mine in the reverberatory furnace.

We shall see how the improvements made, in the construction of the reverberatory furnace and the method of handling, in the substitution of oil for grate-burnt bituminous coal, and, lastly, in the use of fuel dust, have caused reverberatory smelting to be cheaper per ton of charge treated in our smelting centres than blast-furnace smelting.

A. Roasting Furnaces.

The concentrates furnished by the ore-dressing plant contain from 8 to 30 per cent. Cu; they are not rich enough to be smelted direct for a matte with from 40 to 45 per cent. Cu, and have to be rough-roasted to eliminate some sulphur and to oxidize some iron.

Mechanical roasting furnaces are especially suited for the rough-roasting which is to reduce the sulphur content from over 30 to about 10 per cent. Montana smelteries have constructed and operated many mechanical roasting furnaces which embodied various principles for moving the ore over the hearths of reverberatory and kiln roasters. Of the great variety of furnaces, the multiple-hearth MacDougall type has outlived all the others. A MacDougall furnace is a vertical cylinder with superimposed horizontal hearths, central rotating shaft with radial stirring arms provided with rabble-teeth set at a proper angle. The ore, fed mechanically at the top, is turned over by the teeth and moved on one hearth from the periphery toward the centre; it drops through a slot onto the next following hearth, is moved there in an opposite direction and drops through slots near the periphery onto the third hearth; it continues to travel in this manner until it is discharged from the bottom hearth into a receiver. The air necessary for oxidation enters through side doors and travels in a direction opposite to that of the ore.

Of the MacDougall type of furnace, three forms are found at copper smelteries: the Evans-Klepetko, the Wedge, and the New Herreshoff.

The Evans-Klepetko furnace is 16 feet in diameter, 18 feet

high, has 6 hearths, a water-cooled shaft 9 inches in diameter, and two removable rabble-arms to a hearth. The roasting capacity at Great Falls was 40 tons in 24 hours, the arms making 1 revolution in 53 seconds; it is 75 tons in 24 hours since the speed of the arms has been increased to 1 revolution in 38 seconds. With high-sulphur ores the arms are water-cooled, with low-sulphur ores air-cooled; if there is not enough sulphur present, say under 28 per cent., for the ore roast without extraneous heat, a fireplace is added to deliver a flame to the second or third hearth from the top.

The Wedge furnace is 20 feet in diameter, 22 feet high, and has 7 hearths. The characteristics are: a 4-foot air-cooled central shaft, for the support of the air- or water-cooled arms, running on roller-bearings, and a furnace top serving as a mechanical dryer. The capacity is 100 tons ore in 24 hours with 35 per cent. S reduced to 7 per cent.; the number of revolutions of the shaft varies with the character of the ore.

The New Herreshoff furnace is 20 feet in diameter, 23 feet high, has 6 roasting and one drying hearths; the central shaft is 18 inches in diameter, carries hollow rabble-arms having vertical partitions extending to near the end. Air forced in at the bottom of the shaft rises, travels outward in one division of a rabble-arm, returns in the other, is delivered to the air-shaft, 3 feet 4 inches in diameter and enclosing the rabble-arm shaft, warmed, and discharged onto the bottom hearth. The capacity is the same as that of the Wedge furnace.

B. Matting Reverberatory Furnaces.

We have seen that in smelting in the blast furnace C and CO generated from the combustion of the coke are the reducing agents; in the reverberatory furnace S is the leading reducing agent; the carbonaceous fuel burned serves only to furnish the heat necessary for the chemical reactions to take place between ore and flux.

In discussing furnace practice I shall confine my remarks mainly to the modern long-hearth furnace with waste-heat boilers, fed semi-continuously, and fired with coal, oil, and fuel dust.

The immediate forerunner of the modern furnace was a furnace with hearth 50 by 20 feet and grate 10 feet by 5 feet 4 inches, treating three 35-ton charges (*i.e.*, 105 tons) in 24 hours, or

236-pound charge per square foot hearth area, with a fuel ratio of 3 : 1. The charge of hot calcines was dropped from the hoppers in the roof and spread; the side doors were closed and luted, and the fire was urged. When the fusion was completed, the furnace was slightly cooled to stiffen the slag; this was skimmed and part of the matte tapped. Then a new charge was dropped onto the remaining matte and the smelting operation repeated. The new charge cooled the furnace considerably, so that a large part of the eight hours of smelting was taken up to bring the furnace again to a full smelting heat, and then only the remaining part given to smelting proper.

In 1904 Mathewson developed at Anaconda the principle of feeding small charges at short intervals near the fire-bridge of a coal-fired furnace 112 feet long by 19 feet wide (*e.g.*, 15 tons charge every 80 minutes and 3000 pounds coal every 40 minutes); he skimmed slag every 4 hours, allowed a bath of matte to accumulate to the extent of 200 tons, and grated every 4 hours. Some of the matte was tapped when needed for converting. This method of operating kept the temperature uniformly high. The result was a greater tonnage, a higher fuel ratio, and a longer life of the furnace. The furnace with hearth 112 by 19 feet treated in 24 hours 300 tons charge or 302 pounds charge per square foot hearth area with a fuel ratio of 4.8 : 1.

The great advantage of the method of working is striking, and was adopted everywhere.

All reverberatory matting furnaces at present are provided with waste-heat boilers, introduced at Anaconda by Klepetko. The former practice was to burn as little fuel as possible, because the hot gases from a furnace went to waste; with the advent of the waste-heat boiler the practice was reversed, as much fuel as the furnace could stand was burned, and thereby the smelting power greatly increased.

Bituminous coal, run-of-mine or screened, has been the common fuel for the reverberatory furnace. Mathewson has shown that with the best coal available in Montana there was little advantage in increasing the length of a furnace beyond 110 feet, and that 100 feet is a practical limit.

Oil was used as a fuel at Humboldt, Ariz., in 1906; it was adopted at Cananea, Mexico, in 1908; and later at Steptoe, Nev.; Hayden, Ariz.; Garfield, Utah, and at other smelteries. The

advantages of atomized oil over bituminous coal burned on a grate are important. The calorific power is higher, the feeding is continuous, and the loss of heat from the fire-box—estimated by J. W. Richards at over 25 per cent.—is avoided, as the oil is blown onto the hearth. The result is that the temperature obtained is higher, the smelting power greater (400 against 300 tons in 24 hours), the heat efficiency larger and the amount of the flux needed smaller, as slags with a higher percentage of SiO_2, 45 against 40 per cent., can be made on account of the high temperature. The temperature of the furnace at the oil burners is so high that the distance between roof and hearth of furnace has to be large, not less than 6 feet, if the life of the silica roof is not to be abnormally short. On account of the continuous firing and the high temperature, the furnace can be longer than with grate-burned bituminous coal; thus Sörensen put into successful operation at Steptoe, Nev., a furnace with hearth 140 feet long and 19 feet wide in which there were smelted, *e.g.*, from April to July, 1914, per day, 685 tons charge, or 0.2915 ton per square foot hearth area with a consumption of 0.562 barrel oil per ton.

The feeding of oil through high-pressure atomizer burners is simple and clean in comparison with the supplying of coal to a grate and the time-consuming and exhausting work of cleaning grates.

The latest step in the improvement of fuel supply is the use of *fuel dust*. This was tried by Sörensen near Salt Lake City in 1906, and by Shelby at Cananea in 1907–08, but was not successful. D. H. Browne, of the Canadian Nickel Company, took up the matter again in 1909 and concluded that the troubles of Sörensen and Shelby were due mainly to stoppage of flues by ashes and to imperfect feeding of dust; the former was overcome by drying the coal to a water-content of 1 per cent. or less, and by grinding it to a fineness of 95 per cent. passing a 100-mesh screen, the latter by improved apparatus, common with cement kilns in the eastern part of the country. In December, 1911, a reverberatory furnace fired with fuel dust was put into successful operation. The furnace, 112 feet long and 19 feet 9 inches wide, has 5 burners, 3 feet 4 inches apart, treats 450 tons charge in 24 hours with a fuel ratio of 6.77 : 1. In working out the problem, the mode of feeding the ore was changed from the Anaconda manner to dropping the larger part of the charge through 6-inch

pipes in the roof placed 2 feet apart, and the smaller part through four 11-inch openings near the fire-end. The ore delivered at the sides covered the side walls so that ore was smelted on top of the slag-matte bath and along the sides. The ore is fed at one side all the length of the wall, at the other to the tap-hole placed near the throat. The original hearth of magnesite brick now protected by matte and ore has been replaced by the usual siliceous material.

At Anaconda the Browne method of working has been so successful that fuel-dust firing has replaced grate-firing; the smelting has been so cheapened that blast-furnace work, as stated before, has been stopped. The Anaconda furnace, 124 feet long by 21 feet wide, has 5 burners placed 3 feet 3 inches apart, and 6-inch feed pipes on the sides placed 19¼ inches apart for 74 feet from the fire-end; beyond this the furnace requires fettling. The new method of charging has reduced the matte-bath from the original 175 tons to 50 tons. The furnace treats in 24 hours 500 tons charge with a fuel ratio of 7.5 : 1; with grate-firing the smelting power was 260 tons with a fuel ratio of 4 : 1.

The latest Anaconda furnace is 147 feet 2 inches long and 25 feet wide; it has 10-inch feed-holes, 24 inches centre to centre; it is expected to treat in 24 hours 800 tons charge with a fuel ratio of 7.7 : 1.

IV. CONVERTING COPPER MATTE.

The conversion of copper matte, first attempted by Raht in 1866, at Ducktown, Tenn., and made a practical process by Manhès in 1880, forms one of the landmarks in the metallurgy of copper. In the process air in the state of fine division is forced through liquid copper-iron matte held at a temperature of about 1150° C. in a vessel lined with siliceous material; the Fe is oxidized to FeO and simultaneously combines with SiO_2 to Fe_2SiO_4, while SO_2 passes off as a gas. The slag is poured off and the remaining Cu_2S blown, with the result that Cu_2O and SO_2 are found, and the Cu_2O as soon as formed acts upon unoxidized Cu_2S, forming Cu and SO_2. This process was brought to a high degree of perfection in this country, and held its own until 1909, when Pierce and Smith, at Baltimore, succeeded in replacing the easily corroded siliceous lining of the converter by the resistant magnesite brick and adding the silica required for slagging oxidized iron by charging siliceous ore. Basic converting has shown so many advantages over the original acid process that it has

almost entirely replaced the latter. I shall confine my remarks to basic converting.

A characteristic of all matte converters is that they are side-blown, and not bottom-blown, as is the steel converter. There are in operation two classes of vessels, the horizontal and the vertical; typical forms are those of Garfield, Utah, and of Great Falls, Mont.

The Pierce-Smith converter at Garfield is a horizontal cylindrical shell, 26 feet long and 10 feet in diameter, supported by three sets of carrying rollers. The shell is lined with magnesite, holds 30 tons copper, has on the blowing side 32 tuyères with 1.5-inch openings 18 inches above the bottom; at the pouring side there is an opening with spout for introducing the charge and pouring the copper, and at the top is the throat for the passage of the gases into the dust chamber. The cylinder is rotated in a horizontal plane by means of wire ropes.

The Great Falls converter of medium size is an upright cylindrical steel shell, 12 feet in diameter, and, with hood, 13 feet 8 inches high, holding 12 to 14 tons copper. It has 15 2-inch tuyères 12½ inches above the bottom, and a throat for the receiving of charge, the pouring of slag and metal, and the passage of gases. It is carried by two short trunnion-shafts, attached to friction wheels running on friction rollers, and is rotated in a vertical plane by spur wheel and pinion. This 12-foot converter has made such an excellent record that it is being introduced at most smelteries. Great Falls and Anaconda now have 20-foot converters, but most smelteries prefer smaller sizes.

The mode of operating in both vessels is similar. The vessel, suitably prepared and heated, received a certain amount of liquid matte which is followed by a suitable quantity of siliceous ore; it is blown with air at 11 to 14 pounds pressure until the iron is oxidized and slagged; the slag formed is then poured. Fresh liquid matte and ore are charged and blown; these operations are repeated once or twice until the vessel is filled with white metal, *i.e.*, practically pure cuprous sulphide with 80 per cent. Cu; the white metal is now blown in the usual way to blister copper to be poured.

The slag formed contains SiO_2 26 to 28, FeO 50 to 55, Al_2O_3 3 to 4, CaO under 1 per cent.; the blister copper about 99 per cent. Cu.

The Pierce-Smith 26- by 10-foot vessel holds about 40 tons matte; it takes 20 hours to furnish 45 tons blister copper from 45-per cent. copper matte, or, roughly, 30 minutes per ton of copper. The Great Falls 12-foot vessel holds 12 to 19 tons matte; it takes 4 hours and 20 minutes to furnish 13 tons of copper, or 20 minutes per ton copper. Thus the work of the upright is quicker than that of the horizontal; the life of the lining is also longer.

The two leading considerations in the operation of the basic converter are the blowing temperature and the SiO_2-content of the slag. If the blowing temperature exceeds 1150° C., the lining is quickly corroded; hence greatest care is taken to keep the temperature down by regulating the blast, by charging cold copper-bearing materials, or by allowing slag to accumulate in the vessel, as this retards conversion. The SiO_2-content of the slag is of importance, as a low SiO_2 favors the oxidation of Fe to Fe_3O_4, which adheres to the magnesite lining and protects it, while high SiO_2 favors the oxidation of Fe to FeO, which enters the slag and favors corrosion of the lining.

V. FIRE REFINING OF COPPER.

The aim of the process is to remove from metallic copper foreign substances which impair its physical properties. As practically all the copper received by our refineries is converter metal with about 99 per cent. Cu, and cathode metal, which is still purer, the chemical aspect of the process is comparatively simple.

The researches of Wanjukow and Stahl have thrown new light upon this question. They conclude that (1) Zn, Fe, Co, and Sn are completely removed at the beginning of the oxidizing stage, and S at the reducing or poling stage; (2) that the elimination of Ni, Pb, As, and Sb continues through the entire process and imperfect; and (3) that Ag and Bi are removed only to a very small extent.

The operation is carried on in a reverberatory furnace. It involves (1) charging, (2) melting, (3) partial oxidation of the fused metal in order that the Cu_2O formed, which is soluble in copper and has a smaller affinity for O than the foreign substances removable by fire, may oxidize the impurities and cause them to rise to the surface to be skimmed, and (4) reduction of the Cu_2O by poling to give the metal the required degree of malleability and ductility.

The improvements made in the process are mainly mechanical. Formerly the metallic copper was charged by hand and the refined copper ladled. This limited the size of a furnace; through one door 8 tons of metal can be charged per hour; the use of pneumatic lifts increases this amount to 17 to 20 tons. The mechanical chargers of Prosser and Ladd, and Clarke-Antisell handle 150 tons cathodes in 2 hours with 2 men.

Ladling the copper from a 25-ton furnace into ingots weighing on the average 17 pounds takes about 4 hours; ladling with a trolley-supported ladle permits casting twice the amount in the same time. This is about the limit. Furnaces used to hold 15 tons copper, later their capacity was increased to 40 and 50 tons, but this was the limit until A. R. Walker constructed his casting machine, which handles as much as 400 tons copper in less time than is necessary to cast 40 tons with a trolley-supported ladle. With mechanical charging and mechanical casting the size of the charge to-day is governed solely by the ability to construct a furnace, especially a furnace bottom, which will stand such enormous weights, and by the skill of the refiner in holding such a bath of copper at the desired pitch; *i.e.*, that the copper shall not be over- or under-oxidized. Modern furnaces hold from 80 to 400 (usually 200 to 250) tons copper, starting with cathodes, and finishing with ingot, wire bar, and cake copper.

[A number of lantern slides of copper plants, roasting and reverberatory furnaces, converters and other machinery were shown and described during the course of the lecture.]

Locked-up Potash. (*Overland Guidebook*, Bulletin No. 612, U. S. Geological Survey.)—About two miles northeast of Superior, Wyo., are the Leucite Hills, which are made up largely of igneous rocks in the form of volcanic necks, sheets intruded into the stratified rocks, and dikes cutting across the sedimentary strata. Associated with these intrusive rocks are volcanic cones and lava flows. These rocks have long been objects of scientific interest because of their unusual character. Lately they have attracted additional interest by reason of the potash-rich mineral, leucite, they contain, which may some day be utilized if a process can be found for extracting the potash cheaply. It has been estimated that the igneous rock of the Leucite Hills contains more than 197,000,000 tons of potash.

Unusual Features in a Lift Span Bridge. ANON. (*Engineering Record*, vol. 72, No. 22, November 27, 1915.)—Provision for a shifting river channel by using a lift span and five other truss spans of identical design to make possible the future transfer of the towers to lift any span desired, the use of counterweight chains of special design instead of the usual wire cables, and the adoption of a folding cast-iron counterweight to control the balance of the lift span and chains are some of the unique features of the recently-completed bridge over the Arkansas River near Pine Bluff, Ark. The bridge, which is a combined railway and highway structure, is approximately 3010 feet long, with 1610 feet of steel structure and 1400 feet of timber trestle. The steel section consists of seven riveted spans, six of which are 239 feet 4 inches centre to centre of end pins and one 149 feet 7 inches long.

The channel of the Arkansas River is liable to shift at any time. At the Cotton Belt bridge, a few miles below Pine Bluff, the channel shifted from one side of the river to the other, necessitating the construction of a new swing span, so that the bridge now has two swing spans. It was therefore considered desirable in this case to use a type of construction such that the movable span could be shifted to any part of the bridge in case of a change of location of the channel. The spans were accordingly made all alike and provided with all arrangements for attaching the lifting and control mechanisms to any one of the equal spans. The weight of the chains is balanced by disks of cast iron so arranged that they are picked up by the counterweight as it rises, thus adding to its weight to compensate for the otherwise unbalanced length of chain.

Elasticity and Strength of Stoneware and Porcelain. J. E. BOYD. (*Proceedings of the American Society of Mechanical Engineers*, New York, December 7 to 10, 1915.)—The widely-extended growth of elaborate construction work incident to the rapidly-increasing development of electric transmission projects has prompted a closer study into the mechanical properties of the clay products serving as insulating members in electric transmission structures. With the object of making possible the design of insulators of greater mechanical strength and determining a more definite factor of safety, a series of stress-strain tests have been conducted on clay products in tension and compression.

The results indicate that the modulus of elasticity of stoneware and porcelain is practically the same in tension as in compression. The modulus of elasticity of porcelain is about 10,000,000, while that of stoneware ranges from 6,000,000 to 9,000,000, depending on the material. The compressive strength of porcelain and high-grade stoneware in a column 16 inches long and 1 inch in diameter is about 20,000 pounds per square inch. The stress-strain diagram is practically straight up to 7000 pounds per square inch. The tensile strength of stoneware ranges from above 1100 to 2200 pounds per square inch.

THE LIGHT-REFLECTING VALUES OF WHITE AND COLORED PAINTS.*

BY

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Member of the Institute.

THE attention of engineers is being constantly called to the relative value of different types of artificial illuminants for interior spaces. Very little thought, however, has been given to the light-reflecting power of the interior surfaces where such illuminants are used. That the surface constitutes quite as important a factor as the type of illuminant is indicated by the tests herein described, where the illumination of an interior space lighted with a tungsten lamp varied from 12 per cent. to 67 per cent. when different surface colors were used.

Although considerable work has been done on the light-reflecting power of wall papers,[1] the constantly-decreasing tendency to use paper, on acount of its insanitary properties, and the steadily increasing use of wall paints of the oil type, especially in hospitals [2] and public buildings, have necessitated a reconsideration of the problem, since different methods of determination would be required in many cases for two such different substances as paper and paint.

A search of the literature on illumination has produced one article which gives a series of carefully-made photometric measurements on the reflective value of paints. This is by Louis Bell,[3]

* Communicated by the Author.

[1] "Surface Brightness and a New Instrument for Its Measurement," Dow and Mackinney, *Illum. Eng.*, vol. 3, Nov., 1910, p. 655. "Apparatus for Measuring Light and Illumination," Dow and Mackinney, *Elec. World*, vol. 60, Aug. 17, 1912, p. 364.

[2] "The Sanitary Value of Wall Paints," H. A. Gardner, Bull. Scien. Sec. Paint Mfrs.' Assn. of U. S.

[3] "Examination of the Coefficient of Different Tints in Its Relation to Indirect and Semi-indirect Lighting," Louis Bell, *Elec. World*, vol. 65, Jan., 1915, p. 211.

who calls attention to the fact that traces of carbon in a paint (gray) or dust of a painted surface immensely decrease the illuminating value. He advocates the use of light-colored oil paints on account of their washability. Some of his readings are shown below. The composition of the paints is not given, and the colors are only described by terms.

Color	Kind of paint	Per cent. reflection
White	Oil	65.7
Extremely faint cream	Oil	64.0
Light cream	Oil	52.8
Light cream	Water	52.0
Very faint greenish	Oil	46.0
Very faint greenish	Water	45.8
Faint gray	Oil	45.6
Pale-gray buff	Water	44.0

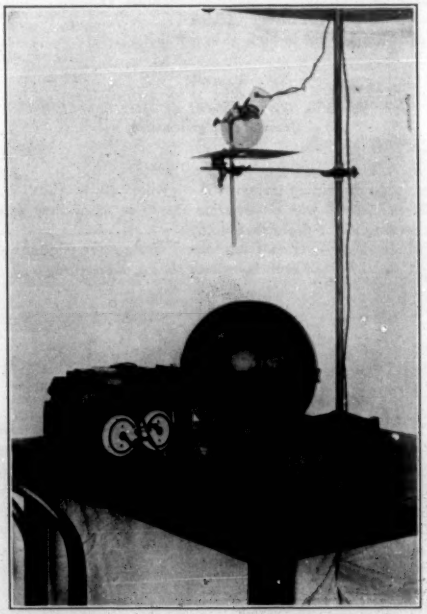
Unfortunately, direct readings on a photometer could probably not be made with great accuracy on very dark paints or on those which present a very high enamel-like lustre. The apparent necessity of devising more appropriate means of measuring the light-reflecting powers of paint, by a method which could be used for all shades and tints, as well as all degrees of matte and gloss surfaces, led the writer to experiment with a number of types of apparatus. Painted samples for experimentation were first prepared by sizing paper and applying two coats of a number of white and colored paints of which the composition was known. The apparatus that proved most suitable for determinations of the "coefficient of reflection" [4] is shown in Figs. 1 and 2, as arranged by W. F. Little,[5] who made the readings. A disk 3¼ inches in diameter, coated with the paint in question, was placed at the centre of an integrating sphere and was illuminated by the light of a concentrated filament lamp shining through an opening in the top of the sphere. The light fell on the disk at an angle of 45 degrees. The interior of the sphere received only such light as had first

[4] Defined in the 1915 Report of the Committee on Nomenclature and Standards of the Illuminating Engineering Society as "the ratio of the total luminous flux reflected by a surface to the total luminous flux incident upon it."

[5] Engineer in Charge of Photometry, Electrical Testing Laboratories, New York.

been reflected by the paint. To effect a standardization a flat block of magnesium carbonate (commercial) was substituted for the disk. The value of the coefficient of reflection of this block was taken as 88 per cent., in accordance with the experiments of

FIG. 1.



Apparatus for determining coefficient of reflection of painted surfaces.

Nutting, Jones and Elliott.[6] The readings were made with a portable photometer. The results are shown in the following tables and on the insert sheet which presents samples of the colored paints on paper.

[6] "Results of Some Possible Reflecting Power Standards" in the *Trans. of the Illum. Engrg. Soc.*, vol. 9, No. 7, 1914.

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TABLE I.

Effect of the Vehicle on the Coefficient of Reflection of White Paints.

	Coefficient of reflection
Lithopone in dark-colored raw linseed oil	61
Lithopone in very light-colored flat varnish	67
White pigment mixture in light-colored semi-gloss varnish	66
White pigment mixture in light-colored gloss varnish	66
Special white pigment in flat varnish	61.2
Special white pigment in high-gloss varnish	61.2

TABLE II.

Effect of Slight Tints on the Coefficient of Reflection of White Pigments Ground in Flat Varnish.

	Coefficient of reflection
Pigment A, free from impurities (very white)	66
Pigment AA, containing traces of iron giving yellow color	64
Pigment AA, tinted with ultramarine blue to correct yellow shade, producing slight greenish tint	64
Pigment A, with 1½ per cent. lampblack tinting color (light gray)	44
Pigment A, with 1 per cent. lampblack tinting color (gray)	27

TABLE III.

Colored Paints.[1]

MADE ON A MIXED WHITE PIGMENT BASE, TINTED WITH CHROME YELLOW, CHROME GREEN, PRUSSIAN BLUE, PARA RED, OCHRE SIENNA, CARBON BLACK, ETC.

	Coefficient of reflection
Light cream	66
Light pink	60
Light yellow	58
Light blue	55
Light greenish yellow	54
Light buff	52
Light green	42
Light terra-cotta	41
Medium terra-cotta	39
Light greenish blue	36
Medium blue	32
Warm green	19
Medium green	14
Red	12
Blue, dark	12
Green	11

[1] The exact color is shown on the insert sheet.

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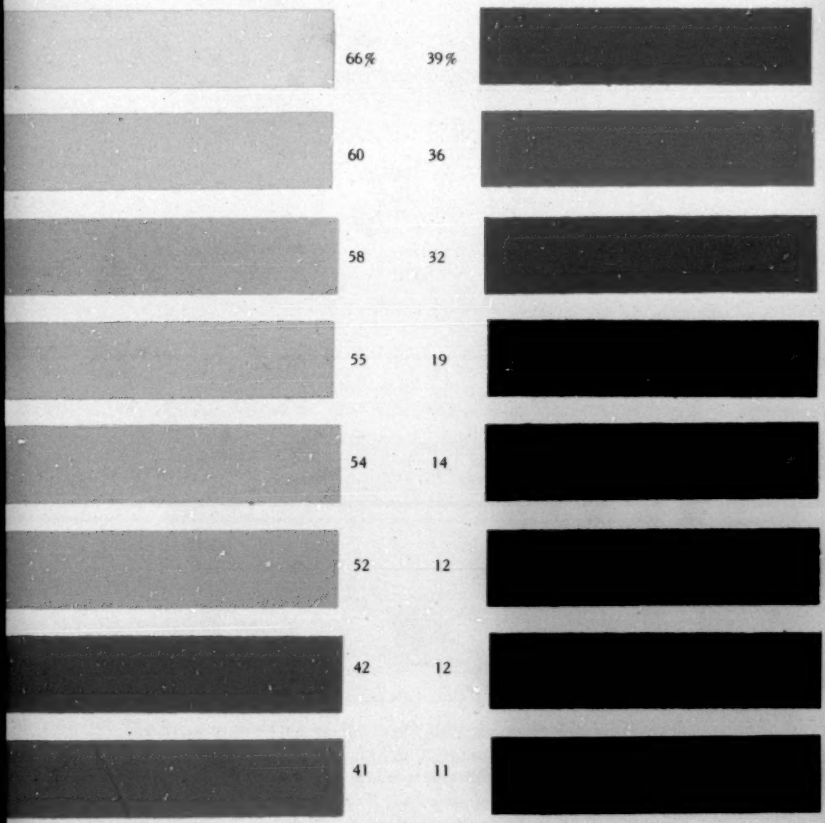
CHART SHOWING COEFFICIENT OF REFLECTION OF VARIOUS WALL COLORS COMPARED WITH A BLOCK OF WHITE MAGNESIUM CARBONATE (88%)



Insert to "The Light Reflecting Values of White and Colored Paints," by Henry A. Gardner.

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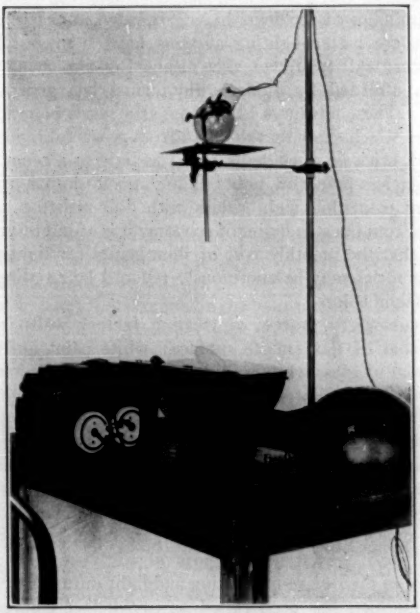
TABLE IV.

	Coefficient of reflection
Luminous calcium sulfid paint	54.4
Aluminum paint	48.

FIG. 2.



View showing painted surface in place within integrating sphere.

The most interesting of the results are those on flat, semi-gloss and high-gloss paints, all of which apparently have substantially the same illuminating value when prepared of the same pigment mixture with oils or varnishes of the same degree of color. This is an important development, since it allows the use of the type of paint best suited for the lighting equipment of a room: direct, semi-indirect, indirect, etc. Although flat paints may retain

their whiteness for a greater period of time, semi-gloss and gloss paints are preferred in many instances on account of their greater resistance to frequent washing.

Factory Illumination.—The illumination of factories, railroad terminals, and department stores has been given great consideration of recent years, increased output, improved workmanship, and a minimum of accidents having resulted in nearly every instance where better lighting systems have been installed. In such places, wall treatment as a means for conserving the illumination afforded by modern illuminants has generally been adopted. These advances have come as a result of practical observations which show that the rays from powerful lights, falling upon dark brick or stone walls, give less light to a room than the rays from less-powerful lights falling upon similar walls that have been painted in light colors with dust-resisting, washable paints. From the standpoint of economy it is of interest to record the fact that the monthly cost of illuminants for lighting dark-walled factories may be enormously reduced by painting the interiors in light colors.

The customary process of treating factory walls is to first apply a coat of flat (matte surface) white paint and later to apply a coat of gloss white. This is the recommended treatment when the modern indirect or semi-indirect forms of lighting fixtures are used, since the gloss finish repels the lodgement of dust and may be most easily washed For the ceilings, however, a flat or semi-gloss paint is better than a high gloss, since the former types distribute the light to better advantage. In factories where direct-lighting fixtures are used with modern illuminants, or where even less-modern forms of illumination are in evidence (swinging oil lamps, etc.), the flat or semi-gloss oil paints are also advisable, on account of their glare-preventing and light-diffusing properties.

The question has been raised as to whether colored paints should be advised for use where direct lighting fixtures are employed, since white is not always the most desirable color under some forms of very strong light. For instance, the traveller who for the first time approaches a tropical city is surprised to see the buildings and dwellings painted blue, pink, green—in fact, every conceivable color. In Havana there exist ordinances prohibiting the use of white paints on the exterior of buildings, on account of the glaring effect produced by the tropical sun. The selection of

the colors is left to the discretion of the property owner. Similarly, it is possible that in some factories paints having a slight greenish or other tint would be desirable, since a small amount of some colors may reduce the glare but will not materially reduce the illumination. The wall tint to be used should, however, be studied under the particular form of light present in a room, since artificial illumination of some types exerts a marked action upon certain colored surfaces,[8] giving them shades or tints which are entirely different from those observed in daylight or by other illuminants. The tint which is most pleasing under the light used, and of sufficient reflective value, should be adopted.

Schoolrooms, Public Buildings, and Dwellings.—A. C. Rapp,[9] of Pittsburgh, was the first to call attention to the necessity of a careful selection of colors for schoolrooms, in order to bring out the greatest mental and physical effort among the occupants. The adoption of his suggestions would doubtless result in greater efficiency in the schoolroom and a higher degree of physical fitness among the students. In his paper Rapp quotes some experiments conducted by Dr. L. E. Landon on students placed in rooms treated with various colors. The effects of the colors may be summed up as follows:

Black.—Melancholia. Decreased work.
Red.—Temporary stimulation followed by a reaction, accompanied by nervousness and headache.
Blue.—Calmness and seriousness.
Green.—Increased vitality. Happiness.
Yellow.—Increased vitality. Amiability.

That the same consideration should be given to the selection of wall colors for all public buildings, stores and dwellings as well as schools, is apparent. It is the writer's contention, however, that the lighter tints of the most desirable colors should be used, in order to increase the illumination to the greatest possible extent. The darker colors could be used for borders and dadoes to produce pleasing contrasts to the main body of the work. These

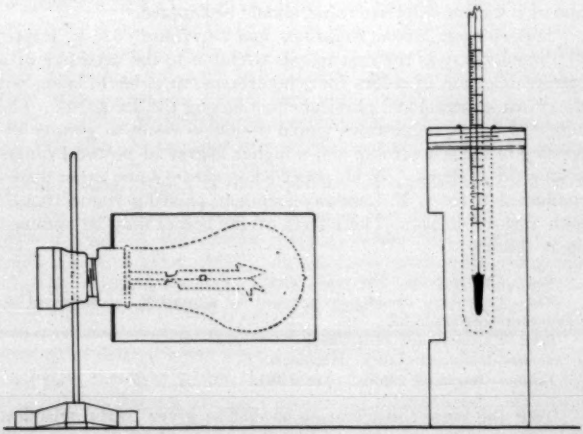
[8] "A Standard for Color Values," D. McF. Moore, *Proc. Illum. Eng. Soc.*, vol. 5, 1910, p. 209. "Reflection Coefficients," P. F. Bauder, *ibid.*, vol. 6, 1911, p 85. "Influence of Colored Surroundings on the Color of the Useful Light," *Elect. World*, 1913, vol. 61, p. 410.

[9] "Surfaces and Colors for Hospitals and Schools," A C. Rapp, Bulletin 38, Scientific Section Paint Mfrs.' Assn. of U. S.

suggestions are in line with those advanced by Parsons and Smith,[10] who studied the physiological effect of colors in study-rooms at the United States Naval Academy. They advocated ceilings painted white, slightly tinted with yellow, and light greenish-yellow walls which by tungsten light would assume a pleasing green color.

Carriers.—Subterranean travel has increased to such great proportions in our large metropolitan centres that the problem of

FIG. 3.



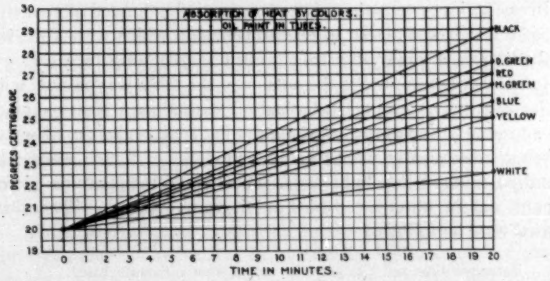
Apparatus for determining heat absorption of various colors.

lighting subway cars is one of growing importance. Every paintable surface in the cars should be coated, preferably with gloss paints in white or the lightest tints. Even the floors should be painted, not with dark-gray or similar light-absorbing colors, but with neutral buff or light tints of sufficient strength to prevent them from being readily soiled. By the use of hard drying, abrasion-resisting paints for this purpose, the floors may be maintained in a sanitary condition by daily washing. The darkest

[10] "The Illumination of Study-rooms," *Elec. Review and West. Elec.*, vol. 57, Aug., 1910, p. 428.

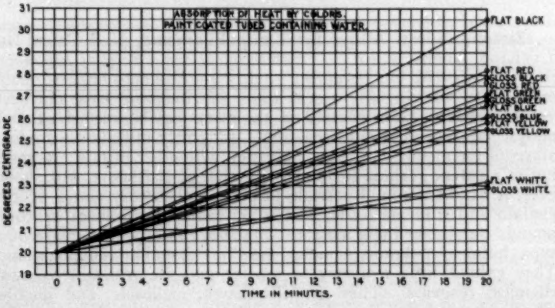
sections of tunnels may be rendered brighter by the occasional application of water-resisting white paints, where the expense of such procedure is justified. Not only in subway cars, but in

DIAGRAM I.



surface cars and railroad passenger coaches, similar paints should be used. The present method of finishing car interiors in artificial mahogany grain could be superseded by the application of

DIAGRAM II.



white and light-tinted paints. Reading at night without eye-strain would then be more of a possibility for the traveller.

Temperature of Colored Surfaces.—Dark-colored paints not

only absorb light rays, but heat rays as well. The presence of only a small amount of black in a white paint (gray) makes an astounding difference in the heat absorption. The writer and L. P. Hart have conducted some tests on those colors which are used by the grinder in producing colored paints on a white base. In one series of tests the colors were ground in linseed oil to a stiff paste which was placed in glass tubes upon which were focussed the rays of a powerful nitrogen-filled Mazda lamp (see Fig. 3). In another series of tests the outside of the tubes was painted with the same colors ground in linseed oil to produce a glossy surface or ground in turpentine to produce a flat surface, 10 c.c. of water being subsequently placed in each tube, all of which were submitted to the same light test. The rise in temperature of the paint and the water is recorded in Diagrams I and II. The colors used were as follows:

Paranitraniline red (20 per cent. on calcium carbonate base).
Chrome yellow, 100 per cent.
Prussian blue, 100 per cent.
Dark green (100 per cent. mixture of blue and yellow).
Medium green (20 per cent. dark green on barium sulphate base).
Black (100 per cent. carbon black).
White (white lead and white zinc, 50 per cent. each).

Zirconium-iron Alloys for Lamp Filaments. U. S. Patent No. 1,151,160, August 4, 1915. (*Metallurgical and Chemical Engineering*, vol. xiii, No. 15, December 1, 1915.)—Attempts hitherto made to produce commercially useful alloys of zirconium have not been very successful, as brittleness of the metal has characterized such alloys. Moreover, it has been found extremely difficult to produce alloys of the metal by direct combination with other metals. According to a patent granted to John L. Brown, of Baltimore, Md., however, it has been found possible to make satisfactory alloys of zirconium and iron and other metals by reducing mixtures of compounds containing these metals. The alloys thus produced are of a type hitherto unknown among metallic zirconium combinations. They exhibit little tendency to oxidize and are resistant to most chemical reagents. They are also tough, malleable, and ductile. The value of these alloys for lamp filaments is that they have the property of selective radiation and possess a remarkably high degree of luminescence at relatively low filament temperatures. The presence of titanium, tantalum, and columbium gives alloys that offer certain advantages for special purposes.

THE PRODUCTION OF LIGHT BY ANIMALS.*

ULRIC DAHLGREN,
Professor of Biology, Princeton University.

LUMINOUS PLANTS.

Most of the unicellular light-bearing forms that we have been considering have some more or less weighty reasons for being called plants. The bacteria were so called on account of their physiological resemblance to the Eumycete fungi, as well as their less fundamental morphological resemblances to the Schizophytes, to which they are more commonly referred by morphological botanists.

Their physiological similarities to the fungi are happy from the viewpoint of the student of luminosity, because we find that the only forms of plant life with an autogenous light production are the fungi.

Light has at times been reported to be generated by diatoms and some flowering plants, but such appearances have been proved to be deceptions, which will be dealt with in a chapter devoted to such false appearances. It is in the fungi alone, then, among the real plants, that we ever encounter any actual organic source of light.

These organisms consist, in their most common individual state, of vast numbers of threads or strands of cells, called Hyphæ, that are massed and woven together in such a way as to form the structures so well known to us as "toadstools," mushrooms, or sometimes simply as fungi. These more apparent parts of the plant that we see in field and meadow rising from the ground, or in the woods projecting from the side of a tree or standing on an old stump or mass of rotting wood, are only the "flowers" or spore-bearing buds of the actual "plant," which consists of a mass of interlaced and branching strands of the woven hyphæ that live all the year round under the surface, away from the light, and deriving nourishment from dead or living organic matter instead of from inorganic matter by photosynthesis, as the majority of plants do (see Figs. 1 and 2).

* Continued from page 127, December, 1915, issue.

This root-like plant that lives and branches out under ground or ramifies between the bark and trunk or through the wood of some infested tree is known as the mycelium. The familiar fruit- or spore-bearing bodies, with their artistic forms and colors, are the toadstools or "fungi," and are known technically as the sporophores or "fruit-bodies" (see Fig. 2).

Of the many hundred species of these fungi, a considerable number of them produce a more or less visible light in all or part

FIG. 1.

Photograph of the mycelium of a parasitic fungus as shown in the wood of a tree trunk by splitting the trunk longitudinally. (After Atkinson, in his book on "Mushrooms.")

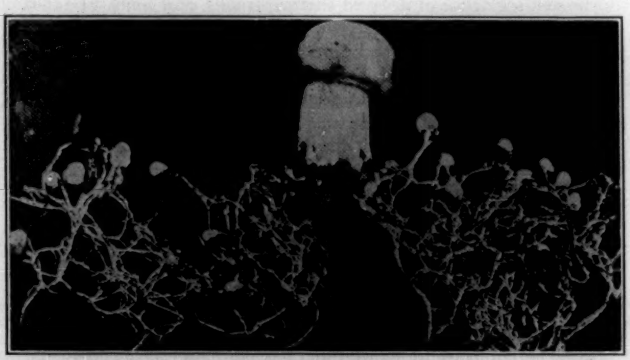
of their bodies and for all or only a certain part of their lives. This fact has been mentioned casually by many writers from the greatest antiquity to the present day, while modern writers have taken the subject up in more or less detail in modern times and studied rather superficially its ecology and physics, but very little of its structural side.

Already the great observers of ancient times had mentioned the luminosity of decaying wood. Aristotle and Plinius have recorded it, although their knowledge of systematic biology was not enough to correctly interpret the phenomenon. Robert Boyle,

Spallanzani, and Alexander von Humboldt studied this question of luminous wood in the seventeenth, eighteenth, and nineteenth centuries and determined several points, such as the necessity of oxygen, and the fact that it was not a heat-producing combustion of the wood. Also, Carradori, Gärtner, Böckmann, and Placidus Heinrich wrote about this luminous wood and remarked upon its odor being like that of most fungi; also, that most all woods, when cut and placed in a moist place, would begin to light under the bark.

Derschau, in 1823, began to show that the light in question was

FIG. 2.



Photograph of an entire mushroom plant to show relation of sporophore or fruit-body to the root-like mycelium from which it grows. (After Atkinson, in his book on "Mushrooms.")

probably of an organic origin when he showed it to emanate from root-like strands in the wood rather than from the real wood substance itself. This structure he called *Rhizomorpha,* and as such it was further studied by Buchof, Noeggerath, Nees von Esenbeck, Schmitz, Theodore Hartig, and deBary, who all came to the conclusion that it was the wood and not the *Rhizomorpha* that shone.

Before most of their papers appeared, however, Heller had published the fact that it was the fungus (mycelium) that lighted and not the wood. He named the fungus *Rhizomorpha noctiluca,* and was followed by others, who gave different names to the particular fungi they found in luminous wood: R. Hartig named it

Rhizomorpha fragilis Roth; Hoffmann called it *Rhizomorpha subterranea,* and R. Hartig, at a later date, identified it correctly as the mycelium of the well-known German fungus commonly called "Hallimasch," and known to science as *Agaricus melleus.*

But this particular mycelium is not the only one that shows light in rotting wood or other organic matter. A large number of others have been found to do the same with varying degrees of brightness. As we will see later, this light is, like the bacterial light, a continuous one so long as the age and condition of the plant permit of its production. These broken and torn mycelia glow and shine as spots and strands of luminous material in the broken substance of decayed stumps, trunks, and limbs of fallen trees in forests all over the world, and have been familiar sights to forestmen, hunters, and others since recorded observations in the literature of many countries and peoples. Their ghostly light has been the subject of fairy stories, superstition, romance, and narratives.

It was soon found that the fruit-body or sporophore of this mycelium does not shine at any time, and the same was proved for some other forms. Collingwood, however, as Hoffmann describes, found a toadstool in Borneo that showed a strong light from both mycelium and fruit-body. The youngest fruit-bodies or buttons shone as brightly as the mycelium, while the light grew dimmer as the toadstool became older. Undoubtedly other fungi are to be found in which the fruit-body alone lights, while the mycelium shows no light at any time.

The luminous forms of fungi are not closely associated, but are members of several widely-separated groups of the Basidomycetæ. The following kinds have been noted as luminous species, either altogether or in some part of their body: *Agaricus melleus,* Europe; *Agaricus olearius,* South Europe; *Agaricus Gardneri,* Brazil; *Agaricus igneus,* Amboina; *Agaricus noctilucens,* Manila; *Agaricus phosphorens,* Australia; *Agaricus prometheus,* Hong Kong; *Pleurotus lampas,* Australia; *Pleurotus illuminans,* Australia; *Pleurotus incandescens,* Victoria, N. S. W.; *Pleurotus nidiformis,* Australia; *Panus incandescens,* Australia; *Collybia cirrhatus,* Bohemia; *Mycena illuminans,* Java; *Omphalia martensii,* Borneo; *Locellina illuminans,* Celebes; *Marasmins sp.,* New Guinea; *Clitocybe illudans,* North America; *Panus stypticus,* North America; *Polyporus noctilucens,* Angola; *Polyporus luci-*

dens, Polyporus annosus, Corticum sp., Dictyophora phalloidea, Brazil; *Xylaria hypoxylon, Xylaria cookei, Tramates pini, Polyporus sulphurens,* and *Illeodiction cerebrum.*

The light from most luminous fungi is not, perhaps, as bright from a given surface as it is in the case of some other organisms. It varies in the different photogenic forms, and, as has been said, is a continuous light whose intensity is varied in only two ways: by controlling the amount of oxygen, and by the time of life and development of the plant.

A good idea of its appearance in one of our American forms, *Clitocybe illudans,* is furnished by a letter sent to the professor of botany at Princeton University in 1900 by an intelligent observer, Mr. Wilfred W. Shaw, who lives in Port Deposit, in the State of Maryland, U. S. A. Part of this letter reads as follows:

"I should be glad to know if the phenomenon is merely extraordinary to me because of my ignorance of botanical matters, or whether it is really of unusual occurrence.

"In a field beside my parsonage—(I am minister of the Presbyterian church at this place)—is growing a clump of fungi. Three days ago my younger boy gathered two, as they were of such a brilliant orange hue, about five inches across; and his mother put them in a small vase on the dining-room mantel-piece.

"That evening I was out and returned home about 11 o'clock; going into the dining-room, where everything was dark, I noticed something luminous on the mantel-piece, and, on making my way across the room, found it to be these fungi. Underneath where the gills are there was a strong luminosity, like a phosphorescent glow. I looked carefully round to see if there was any ray of light coming from any quarter which the fungus might have caught; but there was none. I put my hands close to it; but the light remained the same.

"On Saturday evening I went into the dining-room again to test this light and found the glow to be seemingly just as strong."

Thus we get a good idea of the comparatively strong light emitted by this fungus (*Clitocybe illudans*) (see Fig. 3). Atkinson and other mycologists further describe it as being dark in the very earliest fruit-body stage, brightest at its prime of nearly full size, and the light dying out as its spores are shed and age begins to shrivel it.

A most important point concerning the same species has been

mentioned by Hard in his mushroom book. This plant, in its luminous condition, also generates sufficient heat to make it possible to measure it with an ordinary glass thermometer. Further work should be done on this important point, as the production of heat by practically all other luminous organisms has been shown to be almost a negligible proportion, less than one per cent. in most cases, and only measurable by delicate physical apparatus in the laboratory.

Clitocybe illudans, (Fig. 4) is found in dead stumps and tree

FIG. 3.

Scene in the woods at night, showing *Clitocybe illudans* growing on an old stump (left) and *Panus stypticus* growing on the other side (right). (Drawn by E. Grace White from descriptions.)

trunks on cut forest that has been down for about three years. It is very abundant and is not edible. In color it is a bright yellow or orange on top, with a somewhat lighter stem and gills. As Mr. Shaw has shown, the brightest light is from the gills and casts a glow on the surface from which this toadstool protrudes. Fig. 3 gives a good idea of its appearance in the forest.

The question of the particular part of the fruit-body from which light emanates in fungi has been further looked into by Tulasne, who found that the glow was not superficial, but emanated from the entire internal substance of the luminous fruit-body, al-

though it was brightest as it showed from the gills on the under side. This is probably due to the fact that the form and large surface of the gills or hymenaria of the toadstool allowed more light to radiate, as well as supplied a larger amount of oxygen to the neighboring tissues.

The cells of the hyphæ have been sectioned and studied by the writer and are represented in Fig. 5. While it was not possible

FIG. 4.

Photograph of *Clitocybe illudans* from life. (After Atkinson, in his book on "Mushroooms.")

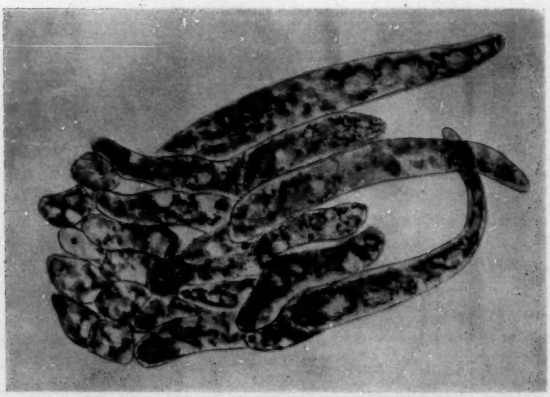
to see the exact source of light in the cells, it is presumed that the luciferine was secreted into the vacuoles shown in the figure, and that the material was consumed as fast as secreted *in situ* in the vacuoles.

In one single species of fungus, however, Volkens has described another method of oxidization. This is a species, *Mycena illuminans*, from Java, and when the luminous fruit-body was examined it was found that the seat of brightest light was in a thick slime with which the upper surface of the cap was covered. Upon

touching it the slime stuck to the hand, and, when withdrawn, the fingers glowed with the luminous substance. This species appears to offer a good opportunity for studies on the chemistry, etc., of the light production.

Another brightly-glowing toadstool is described by Gardner, who while travelling in Brazil, near the town of Natividade, in the province of Goyaz, saw a group of boys one evening playing with some luminous objects that he took at first to be light-produc-

FIG. 5.



Section from the outer part of a "Cap" of *Clitocybe illudans*, showing several hyphæ with their internal structure. Nuclei are very small. Cytoplasm is vacuolated, and luciferine is probably secreted and buried in their spaces. (Drawing by E. Grace White.)

ing insects. Upon looking closer he saw that it was a species of *Agaricus*, afterward named *Gardneri* by Berkeley, and at his request the children took him to the locality in which they had found the fungi. Here he found them growing in large numbers on the leaves of a palm. They were called "Flor de Coco" by the natives, and the light streamed from all surfaces of the plant. As has been said of so many luminous plants and animals, he also said of this, that "one could read by it."

Of all countries in the world, Australia is the one that contains the most numerous and brightest fungi in its forests. Lanterers

describes the brilliancy and abundance of *Panus incandescens* growing in groups on the sides of tree trunks and glowing with an emerald-green light.

Also Alpine describes the light of *Pleurotus candescens* in these same wide forests, growing on half-rotted wood in great abundance. He tells how clumps of this toadstool will glow for at least a week after being gathered in the woods in the month of April. For the first few days the mycelium also glowed near its attachment to the stem, but later only the fruit-body or sporophore was visible as a source of luminosity.

The manner and extent of lighting of the mycelium of several fungi have already been touched upon. In daylight the mycelia of fungi are usually of a translucent whiteness; single small strands in a growing condition are practically transparent. Where the strands are larger, and when strands of any size are numerous and matted together in many layers, the color becomes pure white, like snow, and for the same reason that snow is white, namely, on account of the included air-spaces. Some mycelia are colored, however, and are yellow, black, brown, etc.

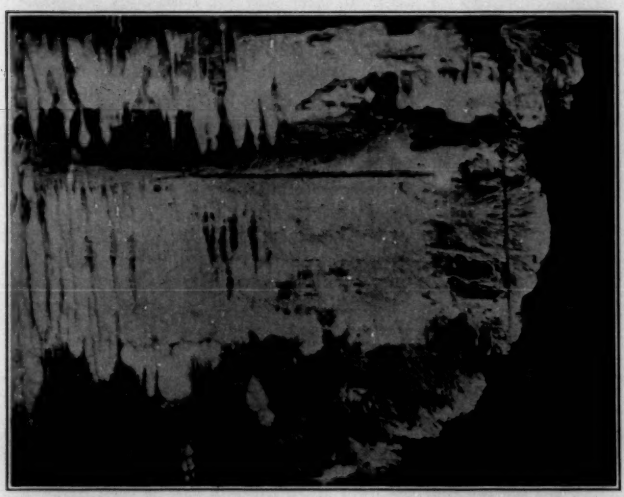
The mycelia are almost always concealed under ground or in earth, manure, or rotten or even living wood (see Figs. 1 and 2). They can almost always be seen by tearing the loose bark off of fallen and half rotten tree trunks or stumps and in the humus of rotted leaves in the forest. They are also found upon the surface of old wood, manure, etc., in caves, mines, etc. Fig. 6 shows a beautiful mycelium growing on the surface of a plank in an abandoned mine near Wilkes-Barre, Pa. Mycelia will also grow when covered by a glass case or bell-jar and kept properly cool and moist on the surface of bread, wood, manure, etc.

Thus we see that the light from mycelia can be seen under a variety of conditions. Most commonly it has been reported and can be seen as luminous spots and threads in moist, rotted-in wood in the forest. Its most vigorous manifestations, however, are visible between the bark and the wood of newly-rotted tree trunks, where it appears in sheets of livid bluish or greenish light when the bark is torn off. A very accurate and natural description of the light under these conditions is given by George Masse, in his "Text-book of Fungi," from an account by Berkeley, as follows:

"A quantity of wood had been purchased in a neighboring parish, and was dragged up a very steep hill to its destination.

Among it was a log of larch or spruce, it is not quite certain which, twenty-four feet long and a foot in diameter. Some young friends happened to pass up the hill at night and were surprised to find the road scattered with luminous patches, which, when more closely examined, proved to be portions of bark or little fragments of wood. Following the track, they came to a blaze of white light which was perfectly surprising. On examination,

FIG. 6.



Photograph of a piece of board from an abandoned coal mine near Wilkes-Barre, Pa. This board is covered with the mycelium of *Agaricus mellens*. (After a photograph by Atkinson in his book on "Mushrooms.")

it appeared that the whole of the inside of the bark of the log was covered with a white byssoid mycelium of a peculiarly strong smell, but unfortunately in such a state that the perfect form could not be ascertained. This was luminous, but the light was by no means so bright as in those parts of the wood where the spawn had penetrated more deeply, and where it was so intense that the roughest treatment scarcely seemed to check it. If any attempt was made to rub off the luminous matter it only shone the more

brightly, and when wrapped up in five folds of paper the light penetrated through all the folds on either side as brightly as if the specimen was exposed. When, again, the specimens were placed in the pocket, the pocket when opened was a mass of light. The luminosity had now been going on for three days."

Where the luminous mycelia of such fungi as *Agaricus melleus* grow on the wooden supports of mines they sometimes show a wonderful brilliancy. At times certain passages in a mine may be entirely covered with such a growth and the resulting light so brilliant that one has no need of any other illumination. Thus Derschau describes the conditions mentioned above as follows: "*Der Steiger bemerkte mir, dass man in dieser Strecke an einzelnen Stellen keiner Lampe bedürfe, indem das Holzwerk hinreichend leuchte. Die Grubenlichter wurden dann gelöscht, und es fand sich wirklich die Strecke stellenweise matt, aber doch so weit erleuchtet, dass man die zu nehmende Richtung erkennen konnte. Bei näherer Betrachtung fand ich das Holzwerk mit bläulich leuchtenden Linien und Punkten überzogen, welche die einzelnen Tierstöcke und Kappen bezeichneten, und an einigen Stellen so hell schimmerten, das ich bei diesem Schein die Fläche meiner Hand wahrnehmen konnte. Meine begleiter wollten dies dem faulenden Holze zuschreiben, so oft ich aber nach jenen leuchtenden Punkten griff, gerieten immer Teile der Pflanze . . . in meine Hand.*"

The luminous mycelium can be used for study in a way that is not possible with the luminous fruit-body. The mycelium lives for years, and it is assumed, in view of our somewhat limited observations and experiments, that the light of a luminous form is continuous so long as active metabolism is going on. We know of no fungoid form that, like the bacteria, is luminous at some times and not at others, even during its healthy growth and reproduction processes.

Molisch, in order to take up the study of the light fungi under favorable laboratory conditions, undertook to make pure cultures in flasks, dishes, etc., on various suitable nutrient media. He was not the first to make cultures of various kinds. Many observers, as Heinrich, learned to place bits of wood in such fashion that they would speedily become inoculated with some luminous mycelium, and elaborate directions were often given for the preparation of such experiments.

Molisch first started by bringing about twenty pieces of barks, stripped from moist, decaying stumps, into the house from the forest. He was careful to keep them moist with wet moss or filter paper, and in the house he placed them under a bell-jar so that they would not dry out and kill the delicate mycelium. Ordinarily the light would last several days or weeks, when the plant would die—for want of food material, in all probability.

He next attempted to transfer small portions of the mycelium from the wood to a richer and more lasting medium, and, with that end in view, he prepared flasks and covered dishes in which were placed portions of sterilized nutrient media, as bread, rice, gelatin, and a sort of broth made from plums, as suggested by Brefeld in some previous work. In some cases agar was used as a base for the plum broth. With a fine needle bits of the mycelium were transferred to the various dishes, and these were then covered so as to exclude so far as possible other fungi, as Penicillium.

Such contamination did occur in many jars, as would be expected, but in several he found the mycelium growing well in pure culture and stretching its creeping arms around, through and over the bread or growing out flat on the surface of the more solid media. One culture was of *Agaricus melleus,* and the growing tips were white, but when the strands were well formed they became light brown to dark brown wherever they were exposed to a fair supply of air. Such parts of the growth as came into contact with glass and such parts as were covered by the fluid that lay on the bottom of the glass remained white. During the growth of the plant small drops of a brownish fluid were exuded from the surface and, these becoming confluent, they formed larger drops that fell to the bottom of the dish and accumulated a considerable amount of the fluid.

Only those portions of the mycelium that were above the fluid showed the power to produce light; and the very young white portions also seemed unable to shine. The period during which a culture could shine was considerable, sometimes over a month. And then a portion of mycelium could be transferred to a new flask with bread and it would grow and go on shining. One mycelium was thus kept in a luminous condition for several months.

This mycelium was, as has been said, the plant of *Agaricus melleus,* and it came to the fruiting condition, as can be seen in Fig. 7. Here we see a flask with some bread on its bottom covered

with the strands of the mycelium. Growing up from this are three sporophores or fruit-bodies that are not light producing in this form.

Another mycelium was found by Molisch and cultivated in the same way for long periods. This plant never came to fructification, and so he never learned its real species. He called it mycelium X and its identity is probably lost forever because even if we find one like it and secure fruit-bodies we can never be sure that it is this particular one. Mycelium X was much lighter in color than *Agaricus*, being, at its darkest, of a light-brown shade.

This form was the most favorable for study because of a greater ease of culture and the superior intensity of its light. One culture in a large flask on sterile bread grew and lighted for over a year and a half. The light was brightest in young, strong cultures, where it was white, according to Molisch.

The light of all known luminous mycelia appears to be intracellular. Molisch concludes this from the fact that the luminous material would not rub off on the hand. He also showed that it was not bacterial in nature.

We have noted that the light of fungi showed some differences in color and intensity. Those differences have been observed with the eye and have, to some extent, been measured by physical apparatus, but by far too little has been done in this direction.

Two observers, Achard in 1783 and Murray in 1827, studied the light of fungi and made the mistake of saying that they were single colored. Achard stated that he came to this conclusion because the light would not pass through colored glasses and also would not break up into constituent rays when passed through a prism. Others have since proved that it would do both these things. Murray was using another form of organic light (insect) in which the spectral extent was still larger, and in consequence his mistake was the greater.

In 1884 Ludwig took up the physical study of the light emanating from fungi, and studied it in four forms of these plants, as well as in the bacterium, *Micrococcus pflugeri*, which he secured from some meat and which he considered as identical with the bacteria found on most sea-fish that have begun to decay. The fungus forms he studied were *Trametes pini* (?), *Agaricus melleus*, *Xylaria hypoxylon*, and *Collybia tuberosa*.

The researches were conducted by means of the Sorby-Brown-

ing micro-spectral apparatus and comparison prisms and measuring apparatus. Also the light was tested by means of glasses colored in blue, green, orange, violet, and red. The spectral qualities of these glasses were determined previously.

FIG. 7.

Glass flask with sterilized bread on its bottom and the mycelium of *Agaricus melleus* growing over and through the bread. Three fruit-bodies have budded out from the mycelium. (After Molisch.)

Examination of *Trametes pini:* Ludwig brought active bits of the mycelium of this form into a dark chamber and found that it was not very bright. The brightest portion was put under the micro-spectral apparatus and upon looking through the objective only a blue shimmer was seen. After his eyes had become ac-

customed to the dark for two hours (!) the outline of the spectral band became visible, and a number of dark lines and one broad dark band crossed it. By turning the prism through which the light from the mycelium came the spectrum of the organic light was brought into a parallel comparison with the spectrum from a ray of light that came from a lighted test candle. This comparison showed that the spectrum of the mycelium light began in the clear blue, from which it extended into the ultra-violet. The dark lines lay in the clear blue, while the broad band was placed in the violet.

The red and the violet glasses allowed no rays to pass through from the mycelium, while they readily allowed part of a weak ray of daylight to be seen through them. A very little of the mycelium light passed through the dark-blue glass, a little more through the orange, and a much larger proportion through the green. This light appeared to come unobstructed through the light-blue test-glass, which same glass cut down the candle-light strongly.

Agaricus melleus was next investigated and with more exact results than, it appears to the writer, in the preceding case. Ludwig describes it as a whitish light with a trace of green. The spectrum was a continuous one (it seemed remarkable that in the preceding case of *Trametes pini* the spectrum should contain dark lines and a dark band) and reached from about 45 to 76 of the Sorby-Browning scale. This was determined by comparison with the spectrum of daylight (later day or evening), by comparison with the absorption spectra of several substances, and measurements with the measuring apparatus, as well as with the various colored glasses.

The transparency of the weak daylight was best through the glasses in the following order: orange, red, violet, blue, and green. That of the *Agaricus melleus* was, on the other hand, as follows: orange, green (fairly good), violet (weak), blue (still weaker), red (not transparent). He noted here that the green glass narrowed the spectrum considerably. This might be expected of any colored glass that cut out any of the wave-lengths produced by the mycelium. Much the same results were attained with the other two fungi, *Xylaria hypoxylon* and *Collybia tuberosa*, and I will merely indicate the principal results.

Trametes pini: Color of light not given. Extent in spectrum, from clear blue to ultra-violet. Exact boundaries not given.

Agaricus melleus: Color of light, whitish tinged with green. Extent of spectrum, from 45 to 76 in Sorby-Browning scale.

Xylaria hypoxylon: Color of light, greenish gold to green. Extent of spectrum, from 55 to 85 in Sorby-Browning scale. One can distinguish the two fungi in the dark both by the eye (color of light) and smell.

Collybia tuberosa: Light weak and could not be accurately placed.

The determination of the color of fungus light by the eye appears to be difficult. Thus Molisch called the light of *Agaricus melleus* and *Mycelium X* "faint white"; according to Kutscher,

FIG. 8.

Four spectral bands shown in comparison: I. Spectrum of sunlight. II. Spectrum of *Bacterium phosphorens*. III. Spectrum of mycelium X. IV. Spectrum of *Pyrophorus noctilucens*. (I-III, after Molisch; IV, after Langley and Very.)

when growing in wood it was "bluish-white." And Molisch called it, under the same circumstances, "bluish-green." Ludwig saw it as "light-blue," and Hartig, "glowing-white." Brefeld described it in forest growth as "whitish tinged with blue." Molisch saw an *Agaricus* from Java as blue-green. Gardner saw the "Flor de Coco" in Brazil as pale-green. Rumph spoke of *Agaricus igneus* as "bluish." According to Tulasne, *Agaricus olearius* shone "like phosphorus." The most pronounced verdict of green color comes from Lanterers, who describes the light of *Panus incandescens* as "emerald green," while Henning speaks of the light from two forms, *Collybium tuberosa* and *Locellina illuminans*, as plain "green."

While allowing for carelessness in defining color and for differences of retinal power to distinguish some shades, it seems fair to state that there are considerable differences in the color of the various fungi. More extended work should be done with accurate instruments in the field, and differences of color should not be stated so emphatically when observed with the naked eye unless a direct comparison side by side has been made.

Altogether it may be said with Molisch that there are slight differences in color and that the fungus light presents a spectral range that is the shortest yet measured, beginning toward the red at the same point that the spectrum of bacterial light does and extending towards the blue a much less distance than that light does. It is continuous and contains no lines as yet determined (see Fig. 8).

(To be continued.)

Solution of Smoke, Fume, and Dust Problems by Electrical Precipitation. L. BRADLEY. (*Metallurgical and Chemical Engineering*, vol. xiii, No. 15, December 1, 1915.)—It is well understood that the smoke, fume, and dust constantly discharged into the atmosphere in the operation of various industries are not only a menace to health and comfort in their vicinity, but also entail a waste of valuable material which would yield a handsome return if collected. The electrical precipitation process developed by Dr. Frederick G. Cottrell has yielded notable results in the solution of this problem. The process consists essentially in compelling the dust- or vapor-laden products to pass between electrodes maintained at a high potential difference.

By this means the particles in suspension become electrified and are attracted and held to such electrodes arranged in the path of the escaping gases. A successful application of the process has been made in an electrolytic copper refining plant near New York City where gold, silver, and other materials are collected as slimes. When these latter are treated in a furnace for the recovery of the gold and silver, a considerable part of these materials was lost as fume. These valuable fumes are now being collected by electrical precipitation, and, whereas previously the actual losses were several thousand dollars per annum, they do not now exceed $300 per annum.

The German Potassium Salts. A. GRADENWITZ. (*Scientific American Supplement*, vol. lxxx, No. 2084, December 11, 1915.)—The remarkable standing of German agriculture is due to the assistance of a highly-developed science rather than to the excellence of the soil or the advantages of a privileged climate. In fact, Nature, in Germany, has, in both respects, been rather sparing with her bounties. However, the country possesses one treasure of inestimable value, viz., its deposits of potassium salts, which are not found in any appreciable amounts outside of Germany and on which the agriculture of the world is to some degree dependent.

The German potassium salt deposits were formed by gradual settling in a branch of the ocean which once covered a large portion of northern Germany. When the saturation of the brine had reached a certain degree, the least soluble salts, carbonate and sulphate of lime, were the first to separate, while the sodium, potassium, and magnesium salts still remained in solution, there being a continued, though not regular, water supply from the ocean. As evaporation advanced, the main part of the rock salt separated in its turn, thus becoming the mighty base of all present potash beds. The mother-lye now contained, besides sodium compounds, only magnesium and potassium salts, which concentrated the more rapidly as the high temperatures and violent storms stimulated evaporation. Magnesium sulphate was the first to separate in what is known as the Kieserite region, above which the potash at last settled in a double salt of potassium and magnesium chlorides, mixed with some sodium salt, known as carnallite, constitutes the main component of the more important potassium salt deposits, and is found in inexhaustible amounts throughout northern Germany.

The potassium salt deposits eventually became covered with an air- and water-tight coating of fine clay, on which a layer of substantial sand and clay settled in the course of time. Great variety was, however, produced in the composition and arrangement of the salt beds by the water entering through any fissures. Apart from carnallite, there are some other potassium minerals of importance to the agriculturist, viz., hard salt, produced from carnallite by the action of water washing away the magnesium chloride; sylvanite, another product of carnallite, freed also of its kieserite and kainite, in connection with which only magnesium chloride has been washed out.

The carnallite, kainite, hard salt, and sylvanite are blasted out of the deposits, 1000 to 3000 feet in depth, by means of explosives, after which they are taken to the surface in cages and ground to fine powders immediately suitable for use as fertilizers. From carnallite these are, however, made by artificial processes—dissolving, crystallizing, and drying—special fertilizers containing a high percentage of potash, of which a 40 per cent. potassium salt is of growing importance for German agriculture.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

THE Annual Report of the National Bureau of Standards has just been issued and contains material of great technical interest to the industries and to the scientific laboratories. The Bureau's activities may be partially judged by the fact that forty-six new publications were issued during the year, not including revised editions of technical papers and circulars. The new publications included five numbers of the *Bulletin of the Bureau of Standards*, which completes the eleventh volume of the scientific papers. There were also issued 25 scientific papers, 10 new technologic papers, 8 new circulars, and 3 miscellaneous publications.

The following new circulars were issued during the year: "Units of Weight and Measure, Definitions and Tables of Equivalents," "Standard Methods of Gas Testing," "Safety Rules to be Observed in the Operation and Maintenance of Electrical Equipment and Lines," "National Standard Hose Couplings and Fittings for Public Fire Service," "Measurement of Time and Tests of Timepieces," "Regulation of Electrotyping Solutions," "Composition, Properties, and Testing of Printing Inks," and "Proposed National Electrical Safety Code."

The following scientific papers were issued: "Testing of Potentiometers," "Emissivity of Metals and Oxides—I, Nickel Oxide (NiO) in the Range 600° to 1300° C.," "Adjustments of the Thomson Bridge in the Measurement of Very Low Resistances," "Quantitative Experiments in Radiotelegraphic Transmission," "Measurements on Standards of Radiation in Absolute Value," "Experimental Study of the Koepsel Permeameter," "Various Modifications of Bismuth-Silver Thermopiles Having a Continuous Absorbing Surface," "Combustion Calorimeter and Heats of Combustion of Cane Sugar, Benzoic Acid, and Naphthalene," "Specific Heat of Copper in the Interval 0° to 50° C., with a Note on Vacuum-jacketed Calorimeters," "Equilibrium in the System: Lead Acetate, Lead Oxide, and Water at 25°," "Watthour Meter Method of Testing Instrument Transformers,"

* Communicated by the Director.

"Insulating Properties of Solid Dielectrics," "Direct-reading Instrument for Measuring the Logarithmic Decrement and Wavelength of Electromagnetic Waves," "Electrical Resistance and Critical Ranges of Pure Iron," "Absorption, Reflection, and Dispersion Constants of Quartz," "Characteristic Equations of Tungsten Filament Lamps and Their Application in Heterochromatic Photometry," "Vibration Electrometer," "Studies on the Silver Voltameter," "Wheatstone Bridge for Resistance Thermometry," "Emissivity of Metals and Oxides—II, Measurements with the Micro-pyrometer," "Emissivity of Metals and Oxides —III, Total Emissivity of Platinum and the Relation Between Total Emissivity and Resistivity," "Comparison of Stellar Radiometers and Radiometric Measurements on 110 Stars," "Temperature Coefficient of Magnetic Permeability Within the Working Range," "Methods of Measuring the Inductances of Low-resistance Standards," and "Emissivity of Metals and Oxides—IV, Iron Oxide."

The following technologic papers were issued: "Industrial Gas Calorimetry," "Iodine Number of Linseed and Petroleum Oils," "Observations on Finishing Temperatures and Properties of Rails," "Analysis of Printing Inks," "Veritas Firing Rings," "Lead Acetate Test for Hydrogen Sulphide in Gas," "Standardization of No. 200 Cement Sieves," "Hydration of Portland Cement," "Study of the Atterberg Plasticity Method," and "Study of Some Recent Methods for the Determination of Total Sulphur in Rubber."

The following miscellaneous publications were issued: "Annual Report of the Director for the Fiscal Year Ended June 30, 1914," "Ninth Annual Conference on the Weights and Measures of the United States," and "Decennial Index to the Bulletin of the Bureau of Standards."

The work of the Bureau involves, among other things, a large amount of testing of standards, measuring instruments, and materials. It involves primarily the investigation of the scientific principles underlying the tests, the study of existing methods, and the development of new standard tests of determinate accuracy. For each test a reasonable fee is charged, except when made for the National or State Governments.

During the fiscal year 1915 the Bureau made 116,204 tests and inspected 1,861,439 incandescent lamps at various factories for

other departments of the Government. Of the total tests, 105,992 were for the Government and 10,212 for the public. The testing was distributed as follows, according to nature of tests: Length measures, 949; mass, 7,529; capacity, 2,230; temperature, 15,734; hydrometry, 2,224; miscellaneous, 153; optical, 1,500; time, 28; electrical, 1,223; photometry, 3,506; chemical, 11,471; engineering (miscellaneous), 878; engineering (instruments), 367; structural materials, 60,989; paper and textiles, 7,359; metallurgical, 64.

FUSIBLE TIN BOILER PLUGS.

An investigation has been completed and prepared for publication on the failure and deterioration of fusible tin boiler plugs. This safety device for preventing boiler explosions is widely used in stationary and locomotive boilers and is required on the marine boilers on all steamboats coming under the jurisdiction of the Steamboat-Inspection Service, which Service brought the matter to the Bureau's attention through the failure of a plug to operate on the steamer *Jefferson*, causing loss of life. Some 1,200 plugs, both used and new, were examined, and this investigation has shown that, although pure tin is called for in the specifications, it often is not furnished by the manufacturer. It appears that only 0.3 per cent. zinc as impurity is sufficient to eventually cause the complete oxidation of the tin filling, thus rendering the plug dangerous, whereas strictly pure tin plugs will remain sound. Several of the specifications now in force are shown to be inadequate. It would probably be well to license a limited number of manufacturers of fusible boiler plugs whose product could be controlled by Federal inspection, and not permit promiscuous manufacture. At present the Steamboat-Inspection Service submits to this Bureau sample plugs from new manufacturers.

PROPERTIES AND STANDARD TEST SPECIMENS OF BRONZES.

The results of the investigation, undertaken at the suggestion of the American Institute of Metals, on the variations in foundry practice as influencing the properties of standard test specimens of the zinc bronze, known as Government bronze of composition 88 copper, 10 tin, 2 zinc, are embodied in a forthcoming technologic paper. The Bureau also has assisted in the preparation of the specifications for this bronze in coöperation with the American Society for Testing Materials. An extension of this work is out-

lined, consisting in the intercomparison of the properties of such specimens prepared from the same ingot metal, but by different foundries, according to a definite and uniform plan of procedure. This will afford information as to variations which may be expected in meeting specifications.

A metallographic examination has also been made, and the results are ready for publication, of the samples of zinc bronze (88 Cu, 10 Sn, 2 Zn) prepared at the Bureau by various methods. It would appear from this investigation that the presence and distribution of oxides in the casting is the predominating factor determining its quality.

This bronze has also been studied to determine its microstructural changes accompanying annealing. The results, which will be published shortly, show that the bronzes are very different in their behavior from steel and show no recrystallization or "grain refining" unless they have been previously cold worked, as by rolling or hammering.

RADIATION FROM METALS AND OXIDES.

The radiation intensities characteristic of the several metals and oxides, or their monochromatic and total emissivities, are of considerable metallurgical and pyrometric importance. The work described in last year's report on "The Emissivity of Nickel Oxide" has since been issued as Scientific Paper No. 224.

The same methods have been applied to iron oxide and published in Scientific Paper No. 249. Iron oxide in the spectral region $\lambda = 0.65\ \mu$ is almost "black," having an emissivity varying from 0.98 to 0.92 in the range 800° to 1200° C. The total emissivity increases from 0.85 at 500° C. to 0.89 at 1200° C. The corrections to be applied to optical and total radiation pyrometers when sighted on iron oxide are as follows:

	500° C.	600° C.	700° C	800° C.	900° C.	1000° C.	1100° C.	1200° C
Optical pyrometer.....	0	0	0	+ 1	+ 2	+ 4	+ 6	+10
Radiation pyrometer ...	+30	+30	+35	+35	+40	+40	+45	....

The micropyrometer (see Scientific Paper No. 198) has also been adapted to the measurement of the monochromatic radiation of metals and oxides, it being possible to take observations rapidly and over a large temperature range on a quantity as small as

0.01 mg. presenting a surface of 0.25 mm.^{2} The results of observations on 23 metals and 12 oxides have been published in Scientific Paper No. 242, showing that, in general, there is no temperature coefficient of emissivity and that for several metals, including platinum, there is a discontinuity in radiation at the melting point. This would render the Violle unit of light, based on platinum brightness at its melting point, a variable standard.

THE QUALITY OF PLATINUM WARE.

The thermoelectric method of classifying platinum ware, described in the last year's report, has been supplemented by measurements on the loss of weight of platinum on heating, with the object of determining the specifications and best composition for platinum ware, such as crucibles, which are subject to loss of weight on heating; a phenomenon which is very troublesome to the analytical chemist and which reduces the accuracy of his results. This investigation, which was undertaken at the suggestion of the American Chemical Society, afforded incidentally an opportunity, through the many samples examined, to form an estimate of the purity of high-grade platinum ware on the American market. Thus, of 164 samples examined, including a wide variety of objects, 43 pieces contained an equivalent iridium content of less than 0.5 per cent. and 110 less than 2 per cent. iridium. The loss of weight on heating for iron-free crucibles ranged from 0.71 mg. to 2.96 mg. per 100 cm.^{2} and per hour at 1200°, the greater losses being for crucibles containing iridium and the lesser with those containing rhodium. From the thermoelectric measurements of purity, combined with a microscopic examination, the probable loss of weight for any platinum crucible can be predicted with sufficient accuracy for analytical purposes. It is suggested, for highest grade crucibles, that iron-free platinum containing 3 to 5 per cent. rhodium be specified. This thermoelectric examination of platinum purity is now a regular Bureau test; also the Bureau's advice has been sought by several departments of the Government and other large users of platinum concerning purchases under this test.

CAUSES OF FAILURES OF RAILWAY MATERIALS.

In conjunction with the engineering and chemical divisions a comprehensive series of investigations of the causes of failure of railway materials has been undertaken, including some of the

fundamental problems in the manufacture, design, and properties of rails, wheels, tires, and axles, as related to their failure in service.

During the past year considerable necessary equipment has been assembled and a start made on several problems, including sound-ingot research, rail-finishing temperatures, transverse fissures in rails, properties of cast iron, thermal analysis, and metallographic methods of examination.

A very important event in this connection was a meeting held at the Bureau, May 22, 1915, attended by the technical representatives of 24 railway systems, at which the work of the Bureau on railway materials was discussed and a plan of cordial coöperation inaugurated, including the furnishing by the railways of statistics of failures and material for examination. It is believed that by thus working in coöperation with the railroads and gaining the benefits of their varied and extensive experience and technical advice, more rapid and efficient progress in the solution of the problems of the causes of failure of railway material will be made. The advantages of a centralized experimental laboratory which also has access to the material in service are manifest.

CAUSES OF FAILURE IN CAR WHEELS.

A study of car wheels is projected in view of the fact that they constitute one of the principal causes of railway accidents, and there are many matters of uncertainty as to best practice in manufacture and design. There are, for example, over 20,000,000 "chilled cast-iron" wheels in use in the United States and they are interchangeable from one railway to another, so that specifications should be rigid and uniform. Some of the items to be studied are statistics, foundry practice, mixtures used in manufacture, effect of sulphur on properties, braking and internal strains, strength of and best design, properties of hot cast iron, soaking pit practice, and relation of combined carbon to annealing. A beginning has been made on the last item.

TRANSVERSE FISSURES IN RAILS.

The problem which the railway conference of May 22, 1915, considered the most urgent is the determination of the causes of "transverse fissures," a hidden defect or split in the rail which often makes its occurrence evident only by the rupture of the rail

by a train. A series of questions on this subject have been submitted to practically all the railroads in the United States, asking for their experience, data and samples, and for suggestions as to methods of attack. The replies which are being received will be a most valuable guide in orienting this investigation, which will involve work in the laboratory, mill, and service, including trials of artificial production of such fissures by several methods, metallographic and chemical surveys of rails containing fissures compared with sound rails, examination of rails which have withstood long, severe service, and the effects of mill practice, including internal strains, gagging, and the completion of the chemical reactions across the rail section as influenced by manufacture. It is also hoped to have the coöperation of the optics division in the determination of the variation of expansion coefficient across the rail section.

FINISHING TEMPERATURES OF RAILS.

The survey of American practice regarding the finishing temperatures and properties of rails, mentioned in last year's report, was presented before the American Institute of Mining Engineers and has been published as Technologic Paper No. 38. The subject of finishing temperatures is one of the greatest importance in rail manufacture, and the discussion of the subject was participated in by several of the most prominent authorities in the country; and this discussion brought out a general confession of ignorance of many matters connected with the relation of methods of manufacture to the resulting properties of rails. It is hoped to be able to aid in the solution of some of these outstanding uncertainties. In Technologic Paper No. 38, the "shrinkage clause" in rail specifications such as those of the American Society for Testing Materials (defining the finishing temperatures by the shrinkage of the rail) was shown not to fulfil the intended requirements of its framers in limiting the temperature to slightly above the recalescence point. The rail committee of the American Society for Testing Materials presented a report concluding "there is lacking anything which points to such decided differences in the quality of rails rolled at varying temperatures as theoretical considerations have led some of us to expect." The society has instructed its rail committee to coöperate with the Bureau in a further investigation of this important matter

It is also proposed to study several allied questions, including the relation of rail section to the temperature distribution on cooling, and the relation of the latter to the completeness of the chemical reactions, internal stresses, and metallographic transformation for different sections and compositions of rails.

SOUND INGOT RESEARCH.

The use of only sound steel ingots for the manufacture of rails and other structures, on which the safety of the public depends, is a matter of the greatest importance. With the coöperation of several steel manufacturers, the Bureau has been enabled to compare the behavior and properties of several types of ingot, including the Hadfield form, consisting in (1) piping steel, (2) cast large end up, (3) suitable sink head with (4) air blast on charcoal and slag. This method produces an ingot, 90 per cent. of which is physically and chemically sound. The results of this investigation, including also an examination of rails rolled from some of these ingots, were presented before the American Institute of Mining Engineers and also before the British Iron and Steel Institute. Opportunity has also been offered for a further study of this type of ingot by the Pennsylvania Railroad, which is to have rolled into rails 100 tons of Hadfield ingots, to be studied in detail by the Bureau.

Arrangements are also being made to study other processes of manufacture of sound ingots, such as the compression process of Mr. B. Talbot, of Middlesborough, England, and the "hot-top" ingots of the Cambria Steel Company, together with an examination of the effects of such ingredients as vanadium and titanium.

It is believed that an impartial study by the Bureau of the methods of manufacture of steel ingots, blooms, rails, and similar products will be helpful in stimulating an improvement in manufacturing methods and should result in more rigid specifications being enforced for those products the use of which involves life hazard.

TEST INGOT INVESTIGATION.

A matter of very great practical importance in the buying and selling of steel, involving acceptance or rejection of the material under specifications, is the determination of its analysis. The usual practice is to take for analysis a "test ingot" from the ladle

before casting and assume this to be representative of the finished product. These test ingots vary greatly, however, in shape and size and quality, and it seemed desirable to endeavor to standardize this practice.

The study has been continued during the past year with the coöperation of the American Society for Testing Materials. Data have been collected regarding American practice in the matter of the shape and size of such ingots, methods of sampling, etc. Seventeen of the leading steel companies have coöperated in the work by furnishing sample ingots of various grades of metal. This first series examined represents ingots poured directly; that is, without the addition of aluminium, silicon, or other substances for rendering the metal compact and free from blowholes. Later the influence of such additions will be considered.

Fifty-five ingots have been examined up to date. This examination, so far, has been entirely metallographic, including the mapping out of the regions of segregation of sulphur (as an index of the segregation in general) and the determination of the presence of included "scale," oxides, etc., in the porous metal. Careful chemical surveys of selected types will supplement and confirm this work. Up to the present the investigation seems to warrant the conclusion that shape and size of the ladle ingots are minor factors and that the investigation of the subject of additions to the metal upon pouring to render the ingot sound and free from holes is the most satisfactory solution of the problem.

This work should be extended eventually by a comparison of "test ingot" analysis with that of the finished products. It would appear that, at least for certain classes of materials, such as rails, the "test ingot" method of analysis should be rejected in favor of the analysis of the finished product.

FOREIGN RAILWAY SPECIFICATIONS.

A technological paper has been prepared on foreign railway specifications for rails, wheels, axles, and tires. This material was collected with the aid of the Department of State from the Governments or railway administrations of Austria-Hungary, Belgium, France, Germany, Great Britain, Holland, Italy, Russia, and Sweden. The circular contains a comparison and discussion of these specifications, including a summary of accident statistics, as well as translations of the foreign text of the specifications

for rails, wheels, axles, and tires. It is expected the circular will be of interest to those responsible for and interested in the specifications for such railway material in the United States. In general, it may be stated that the foreign railway materials, such as rails, wheels, tires, and axles, appear to perform the duty imposed upon them in a more adequate manner than is the case in America.

FAILURE OF STRUCTURAL BRASSES.

A comprehensive study of the causes of failure in service of structural brasses and bronzes has been undertaken by the Bureau. The costly experience of the New York Board of Water Supply on its Catskill Aqueduct project as well as the failures of bronze in the Minneapolis filter plant and elsewhere, the former of which has been widely advertised, raised the questions whether the bronzes used for such structural purposes were suitable for the purposes for which they were designed, whether the specifications were inadequate, or the methods of manufacture at fault. There appears to be a very serious lack of reliable data upon which to draw up specifications for this type of material and the ordinary tests do not usually give an indication of the true permanency of such bronzes which may easily be spoiled in manufacture.

The Bureau has had the coöperation of a number of brass and bronze manufacturers who have furnished material made, as suggested by the Bureau, in several ways; and the Bureau has been able to obtain failed material from several sources, including the New York water board, city of Minneapolis, and the Navy Department.

The relation of the presence of internal stresses to methods of manufacture and subsequent heat treatment have been carried out for numerous samples from various sources. It would appear that the presence of these internal stresses, sometimes associated with corrosion, is largely responsible for failure. It has also been shown these stresses can be removed by annealing, without serious detriment to the physical properties. The effects of corrosion on stressed brasses is also to be studied. There is in this problem of defining the just limitations of non-ferrous alloys for structural and other purposes a wide field of research.

A preliminary account of the work already done is being prepared for publication.

PREPARATION OF PURE IRON AND IRON CARBON ALLOYS.

It is shown that previous work on the iron-carbon diagram is unsatisfactory because of the great variation in the materials used. It was, therefore, thought necessary to produce a series of alloys of great purity to form the basis of a redetermination of the diagram at the Bureau of Standards. The general method consisted in melting electrolytic iron with sugar carbon in magnesia crucibles. The electrolytic iron was prepared from ingot iron anodes in a chloride bath with or without the use of porous cups. The operation of melting the iron with carbon gave great trouble at first because the ingots obtained were full of blowholes and contained considerable quantities of impurities. These difficulties were overcome by melting in a vacuum furnace and making crucibles of especially pure magnesia, made and calcined at the Bureau of Standards. A satisfactory procedure was finally worked out and a series of alloys prepared of the composition Fe + C = 99.96 per cent.

THE IRON-CARBON EQUILIBRIUM.

During the early part of 1914 work on the thermal analysis of pure iron was completed and the thermal study of the iron-carbon series was started. A large number of alloys ranging from 0.02 to 1.8 per cent. carbon were made up and observations taken by the inverse rate and derived differential methods for some 250 heating and cooling curves. These observations have all been plotted and a study of the effect of rate on the location of the critical points has been started. Upon the completion of this work and a study of the effect of decarbonization, the results will be ready for publication. Work on this problem has been delayed or interrupted by the preparation and installation of exhibits for the San Francisco Exposition and by testing.

DETERMINATION AND DISTRIBUTION OF CARBON IN STEELS AND IRONS.

The improvement of analytical methods in metallurgical chemistry are of great economic significance as well as of scientific interest. Two methods for the rapid determination of carbon in steels have been devised, one by direct combustion in oxygen at high temperatures, a preliminary account of which has been published; the other by a conductivity titration method, which is in preparation.

The relation of the amount of graphite to the heat treatment of cast iron is of importance in the manufacture of chilled cast-iron wheels. Some preliminary work has been done in coöperation with one of the wheel manufacturers.

THE PHYSICAL PROPERTIES OF PURE IRON AND COPPER.

The pure iron made at the Bureau is being studied for several of its physical properties. Scientific Paper No. 236 has been published describing the experiments on the electrical resistance and temperature coefficient of pure iron between 0° and 950° C. These experiments, carried out with a precision of 1 in 300,000, demonstrate the non-existence of transformations below 757° C., show the Ac_3 and Ar_3 transformations to begin at the same temperature 894° C. and extend over 25°, and accompanied by a decrease in resistance on heating and an increase on cooling through the A_3 transformation. The A_2 transformation, the interpretation of which is still in dispute, is evidenced by a very sharp cusp at 757° C. in the temperature coefficient curve, or by an inflexion in the resistance curve.

Exact measurements have been taken of the resistance of copper in the interval 0° to 100° C. with the object of detecting allotropic changes which have been reported by Prof. E. Cohen, of Utrecht.

MELTING POINTS OF STEELS AND REFRACTORY ELEMENTS.

The determination of the melting points of a considerable number of steels of practical importance has been undertaken and is nearly complete. Also the melting points have been determined, by means of the micropyrometer, of practically all of the refractory chemical elements. It is hoped to be able to publish these results shortly.

A TEST OF A SURFACE COMBUSTION FURNACE.

In view of the fact that the surface combustion process appeared to offer many advantages for high-temperature laboratory furnaces, in which the Bureau is interested, it was decided to submit a crucible furnace of this type to a thorough test. For the purpose, the furnace was equipped with meters on the gas and air lines, and with a chimney to permit the collection of flue-gas samples. In several runs the mixture proportions were maintained constant while varying the rate of gas consumption. Tempera-

tures were read by a Holburn-Kurlbaum optical pyrometer. The highest temperature reached was 1675°, at which point the muffle failed. The test established that complete combustion could be attained without excess air, that the best air-gas ratio was 5.5, and that a 20 per cent. excess of air caused a lowering of furnace temperature of 100°. An account of this test, which is the first of its kind, is in course of preparation.

NOMENCLATURE OF NONFERROUS ALLOYS.

A paper which evoked considerable discussion was presented before the American Institute of Metals on the "Progress in the Nomenclature of Alloys." There is great need for systematizing the naming of complex alloys and of their constituents. The coining of new names and the use of proper names is being discouraged, and it is probable that from the several suggestions which have been made a rational system of nomenclature may be worked out which meets the needs of the foundryman on the one hand and is correct scientifically on the other hand. The Bureau of Standards in coöperation with the American Institute of Metals is considering the matter, and it has been hoped to bring about uniformity for the English-speaking countries through the coöperation of the British Institute of Metals and its allied societies; and possibly, at least as concerns some of the fundamental principles, international agreement may be reached through the active advocacy of the subject by the editor of the International Journal for Metallography.

INVESTIGATION OF MOULDING SANDS.

In coöperation with the American Institute of Metals, the Bureau has begun an investigation of the properties and methods of testing molding sands, with the object of finding out the characteristic qualities of such sands as have proved serviceable and endeavoring to put on a better scientific basis the classification of molding sands. A preliminary report will be presented at the fall meeting of the American Institute of Metals.

CO-OPERATION WITH MANUFACTURERS ON NONFERROUS METALS.

A very important feature of the work in metals at the Bureau has been the coöperation with manufacturers on non-ferrous metals, including representatives of the American Institute of

Metals, the American Chemical Society, the American Institute of Mining Engineers, the American Society for Testing Materials, and the American Electrochemical Society. Two well-attended meetings have been held during the past year at the Bureau, which has greatly aided in suggesting and mapping out lines of work, securing typical materials or samples, and obtaining the aid and benefit of the experience of many manufacturers for several problems in which the Bureau is interested.

SYSTEMATIC INVESTIGATION OF THE PROPERTIES OF METALS.

Knowledge of the properties of even the more commonly used metals and alloys, especially at high temperatures, is very meagre, and their determination requires, in many cases, elaborate and costly experimental arrangements and considerable skill.

Pulp from Cotton Stalks. ANON. (*Scientific American*, vol. cxiii, No. 23, December 4, 1915.)—A use for cotton stalks, heretofore considered valueless and a troublesome feature incidental to the growing of cotton, has finally been developed, and, although the industry is only beginning, it promises to be an important one. Already a plant is being erected at Greenwood, Miss., which will be devoted to the preparation of pulp from cotton stalks. The cotton stalks, after being converted into pulp, are to be used in the place of wood pulp in paper making. Because of the stronger fibres of the cotton-stalk pulp, it is said that paper manufactured from the cheaper pulp is considerably stronger than that produced from the usual wood pulp. The use of cotton pulp is not limited to the making of paper; it is also applicable to the production of gun cotton and other cellulose materials.

Wet Collodion. ANON. (*British Journal of Photography*, vol. lxii, No. 2898, November 19, 1915.)—There are, perhaps, relatively few workers in the photographic art, accustomed to the convenience and undoubtedly excellent results of the dry plate or film, who realize what an important place the old wet collodion process still holds in commercial photography. The description in this article of the practice of the process, with its multiplicity of detail and minutiæ of manipulation, would indeed discourage any one for whom the modern method will suffice. But for process-work, lantern slides, and other subjects requiring the maximum precision in the distribution of contrasts, the wet-plate process, with all its difficulties, retains an undisputed field.

NOTES FROM THE RESEARCH LABORATORY, EASTMAN KODAK COMPANY.*

THE STRIPPING OF GELATINE DRY PLATES.[1]

By S. M. Furnald.

THE following method is recommended:

A solution is made as follows:

4 per cent. sodium fluoride	2 parts
Formaline (40 per cent. formaldehyde)	1 part

The portion of film to be stripped is first cut around with a knife. The solution of fluoride and formaline may be flowed over the plate or applied with a camel's-hair brush to the portion of film to be stripped. The film will become loosened from the glass in about one minute, and may then be easily lifted by applying over it a piece of dampened paper, lifting carefully one corner and stripping the paper and film away together.

If reversal of the film is required, it is easily transferred to a second piece of paper and from that to the final support.

The glass on which the film is to be laid should be perfectly clean and flowed with a 5 per cent. solution of gum arabic. A little glycerine added to the gum solution tends to improve the condition of the stripped film, which otherwise becomes rather over-dry and horny, owing to the formaline.

With small portions of film there is very little danger of distortion or tearing, but if the plate is first bathed for ten minutes in formaline before applying the stripping solution, the film will strip equally well and is tougher and less liable to distortion.

When stripping large films the plate may first be flowed with

Collodion	30 c.c.
Glycerine	2 c.c.

and, so soon as the collodion film has become set, flowed or immersed in the fluoride and formaline solution; the time required for loosening the film may be slightly longer, but this method gives a tough, rubbery film, considerably stronger than film stripped without the collodion coating.

* Communicated by the Director.

[1] Communication No. 34 from the Laboratory.

Grinding Wheels. W. C. GOLD. (*Metal Industry*, vol. 13, No. 11, November, 1915.)—Previous to the advent of the grinding wheel made from artificial or natural abrasives, manufacturers were dependent upon the natural quarried grindstone. In 1890 emery wheels only were manufactured. The abrasive employed was Turkish emery, now used only for polishing purposes. In 1892 emery from the island of Naxos (Grecian Archipelago) came into use, and for some years proved the best material for the manufacture of grinding wheels.

The first artificial abrasive was "carborundum" or carbide of silicon, manufactured by the Carborundum Company, of Niagara Falls, N. Y., which began business in 1891. Under the name of "aloxite" this firm placed upon the market an artificial corundum in 1909. The Norton Company, of Worcester, Mass., in 1906, abandoned the use of emery entirely and adopted its new artificial abrasive, which it calls "alundum." "Boro-carbone" is made in southern France, where an immense deposit of bauxite exists, and is shipped to the Abrasive Materials Company, of Philadelphia, and there manufactured into grinding wheels and bricks. This product was placed upon the market in 1913.

There are to-day thirty plants, large and small, manufacturing grinding wheels in the United States and Canada. Emery, though still used to some extent, has been largely supplanted by the artificial abrasives, and the carbide of silicons and aluminous oxides of clay or bauxite have come into extended use. So indispensable have grinding wheels become in the realm of manufacturing that many consumers have stated that they would be low-priced if sold at list prices only.

Copper Plating as Used for Purposes Other than Ornamental. E. G. LOVERING. (*The Metal Industry*, vol. 13, No. 11, November, 1915.)—The automobile trade in general is installing copper-plating plants for the electro-deposition of copper on automobile parts, such as cam shafts, gears, etc., previous to heat treatment and hardening. The blank gears and forged cam shafts are sent to the copper-plating department and given a heavy deposit of copper. After they have been machined, they are hardened by the cyanide hardening process, which does not penetrate the (unmachined) parts which have a deposit of copper, but leaves them soft, while only the exposed parts, such as the cam faces and gear teeth, are hardened.

Parts that require a driving fit are given a deposit of from 0.001 to 0.004 inch in thickness and then driven into place, thus making a fit that cannot become loose by vibration. Wire wheels, spokes, radiators, and other parts are given a coating of copper previous to painting and enamelling operations. The bath employed is a combined cleaning and plating bath into which the objects may be immersed without any preliminary cleaning after the machining or other manufacturing operations.

THE FRANKLIN INSTITUTE

(*Proceedings of the Stated Meeting held Wednesday, December 15, 1915.*)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, December 15, 1915.

PRESIDENT WALTON CLARK *in the Chair.*

Additions to membership since last report, 19.

Mr. George H. Clamer, Chairman of the Committee on Science and the Arts, reported the condition of its work.

The following nominations were made for officers and managers to be voted for at the annual election to be held January 19, 1916:

For President (to serve one year), Walton Clark.

For Vice-President (to serve three years), Henry Howson; (to serve two years), Louis E. Levy.

For Treasurer (to serve one year), Cyrus Borgner.

For Managers (to serve three years), Francis T. Chambers, W. C. L. Eglin, Alfred C. Harrison, Charles A. Hexamer, Robert W. Lesley, Marshall S. Morgan, Robert S. Perry, and E. H. Sanborn; (to serve two years), Kern Dodge; (to serve one year), William C. Wetherill.

The Chairman appointed the following members to act as tellers of the election: Messrs. W. N. Jennings, George S. Cullen, and Henry F. Colvin.

Mr. Louis E. Levy, on behalf of the Board of Managers, presented a minute on the death of Vice-President James Mapes Dodge.*

Dr. Alexander Crever Abbott, Director of the Laboratory of Hygiene, University of Pennsylvania, Philadelphia, presented the paper of the evening on "The Transmissibility of Diseases and the Public Health." The manifold channels of transmission of diseases, as well as the methods used, in some cases, in the destruction of the morbific agents of disease, and in others for their utilization to a good end, were fully described. Tables and statistics were presented which indicated that pure water, coupled with better drainage systems, had materially reduced typhoid fever, small-pox, diphtheria, and many other diseases in the large cities. Diseases transmitted by milk and other foodstuffs were also given consideration, as was the rôle of the house-fly and mosquito as carriers of bacterial infections. The subject was fully illustrated by numerous lantern slides.

Mr. Levy remarked that the meetings of the Institute were usually signalized by important presentations on subjects of a more or less technological nature which, while of great significance to all workers in the

* See page 151.

field of the applied sciences and of interest to all who realize the importance of these applications in our modern industrial life, could be fully appreciated only by those engaged in the special branch of science under discussion. But the subject of Dr. Abbott's lecture came home to us all. It dealt with a matter of prime importance to every individual, the life, health, and happiness of every member of the community. The Institute was very fortunate in receiving this highly valuable addition to its present course of lectures. Mr. Levy moved that the thanks of the Institute be therefore tendered the lecturer. This motion, largely seconded, was unanimously adopted, and the President thereupon conveyed the thanks of the Institute to Dr. Abbott.

Adjourned.

R. B. OWENS,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of the Stated Meeting held Wednesday, December 1, 1915.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, December 1, 1915.

MR. G. H. CLAMER *in the Chair.*

The following reports were presented for final action:

No. 2617.—Permutit. Elliott Cresson Medal to Dr. Robert Gans, of Pankow, near Berlin, Germany, adopted.

No. 2626.—Dorr's Hydrometallurgical Apparatus. Final action on this report was deferred until next meeting.

No. 2635.—Northrup's High Temperature Investigations. Final action on this report was deferred until a later date.

No. 2636.—Lenker's L-E-Vation Rod. Edward Longstreth Medal of Merit to Will G. Lenker, of Sunbury, Pa., adopted.

R. B. OWENS,
Secretary.

SECTIONS.

Electrical Section.—A joint meeting of the Section and of the Philadelphia Section of the American Institute of Electrical Engineers was held in the Hall of the Institute on Thursday, December 2, 1915, at 8 o'clock P.M. Mr. H. A. Hornor, of The Franklin Institute, and Mr. J. H. Tracy, of the

American Institute of Electrical Engineers, presided jointly. The minutes of the previous meeting were read and approved as published.

John D. Ball, E.E., of the Consulting Engineering Department of the General Electric Company, Schenectady, N. Y., delivered an address on "Magnetic Investigations of Iron and Steel." It was demonstrated that the failure of sheet steel to follow the Steinmetz hysteresis law at high inductions is due to the presence of impurities, such as scale, which in themselves follow the law but have different constants. The results of tests on scale-free material were reported, and the chemical, physical, and magnetic properties of the scale were discussed. A short *résumé* was given of the results of tests made with unsymmetrical loops, where the mean induction is other than zero, as in apparatus used in rectified circuits, inductor alternators, etc. The lecture was illustrated with lantern slides. After a discussion of the paper by Dr. Hoadley and others, a vote of thanks was extended to the lecturer, and the meeting adjourned.

JOSEPH S. HEPBURN,
Acting Secretary.

Mechanical and Engineering Section.—A meeting of the Section was held in the Hall of the Institute on Thursday, December 9, 1915, at 8 P.M. Mr. George R. Henderson, president of the Section, occupied the chair.

Professor W. F. M. Goss, D.Eng., Dean of the College of Engineering, University of Illinois, Urbana, Ill., Chief Engineer of the Association of Commerce Committee of Investigation on Smoke Abatement and Electrification of Railway Terminals, Chicago, Ill., delivered a lecture, entitled "Smoke as a Source of Atmospheric Pollution." Professor Goss gave a brief account of an elaborate study of smoke and of atmospheric pollution in the city of Chicago, including an analysis of the amount of fuel consumed in the several different classes of service, such as in power plants, in locomotives, in manufacturing industries, and in domestic heating; of the character and amount of smoke arising from these different services; of the effects of smoke, and of the possibilities presented by the existing state of the art whereby the smoke of a modern American city may be abated.

After an interesting discussion, a rising vote of thanks was extended the speaker.

Adjourned.

T. R. PARRISH,
Acting Secretary.

MEMBERSHIP NOTES.

(*Stated Meeting, Board of Managers, December 8, 1915.*)

ELECTIONS TO MEMBERSHIP.

RESIDENT.

MR. F. J. LEMAISTRE, Ridley Park, Pennsylvania.

DR. THOMAS D. COPE, Randal Morgan Laboratory, University of Pennsylvania, Philadelphia, Pa.

NON-RESIDENT.

DR. RAYMOND F. BACON, Director, Mellon Institute of Industrial Research, University of Pittsburgh, Pittsburgh, Pa.
MR. J. T. BAKER, Phillipsburg, N. J.
MR. JOSEPH BANCROFT, Wilmington, Del.
MR. HOLGER V. BERG, Newport, Del.
MR. CHARLES S. BERNARD, No. 2, Allentown, Pa.
PROF. WILLIAM FREAR, State College, Pa.
DR. F. W. FRERICHS, Herf & Frerichs Chemical Company, St. Louis, Mo.
DR. HAROLD H. FRIES, 92 Reade Street, New York City, N. Y.
DR. WILLIAM J. GIES, 437 West Fifty-ninth Street, New York City, N. Y.
DR. MOSES GOMBERG, 725 Oxford Road, Ann Arbor, Mich.
MR. HARRY KIPPENBERG, care of Merck & Company, Rahway, N. J.
MR. JOHN D. PENNOCK, 2002 West Genesee Street, Syracuse, N. Y.
DR. WALTER F. RITTMAN, care of U. S. Bureau of Mines, Pittsburgh, Pa.
MR. C. P. SCHLICKE, 440 Washington Street, New York City, N. Y.
DR. HUGO SCHWEITZER, 410 Riverside Drive, New York City, N. Y.
DR. JOKICHI TAKAMINE, Equitable Building, New York City, N. Y.
MR. CHARLES A. WEST, 14 Fulton Street, Boston, Mass.

CHANGES OF ADDRESS.

MR. GEORGE S. BARROWS, 275 West Exchange Street, Providence, R. I.
MR. R. B. CARNAHAN, JR., 710 South Main Street, Middletown, Ohio.
DR. DAVID T. DAY, Adams Building, 1333 F Street, N. W., Washington, D. C.
MR. BYRON E. ELDRED, Commercial Research Company, Goodyear Building, Long Island City, N. Y.
MR. A. E. GIBBS, care of Pennsylvania Salt Manufacturing Company, Widener Building, Philadelphia, Pa.
MR. WEBB L. GIBBS, 7734 South Shore Road, Chicago, Ill.
MR. CLARENCE A. HALL, 1935 Chestnut Street, Philadelphia, Pa.
MR. GEORGE R. HENDERSON, 1321 Walnut Street, Philadelphia, Pa.
MR. RICHARD HOWSON, 401 Woodlawn Avenue, Wayne, Delaware County, Pa.
MR. JOHN J. KOHLER, Allenwood, Union County, Devitt's Camp, Pa.
MR. CHARLES W. MCMEEKIN, 1270 Pine Street, San Francisco, Cal.
DR. EUGENE L. MAINES, 799 Putnam Avenue, Brooklyn, N. Y.
MR. ROBERT S. REDFIELD, Wayne, Pa.
MR. W. F. THORNTON, Mechanicsburg, R. R. No. 2, Pa.
DR. L. M. TOLMAN, 1831 Wesley Avenue, Evanston, Ill.
MR. CHARLES S. VADNER, 22½ West Seventh South Street, Salt Lake City, Utah.
MR. HENRY W. WILSON, 605 Franklin Building, 133 South Twelfth Street, Philadelphia, Pa.

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John T. Morris

NECROLOGY.

John Thompson Morris was born July 12, 1847, and died August 15, 1915.

The death of John Thompson Morris, a life member of The Franklin Institute, was the subject of a special minute adopted by the Board of Managers of the Institute at its meeting on October 13, 1915, and published in the November issue of the JOURNAL. The following memoir is supplementary to that publication:

John Thompson Morris was the son of Isaac Paschall Morris and Rebecca Thompson Morris, of Philadelphia. He was educated at Haverford College. He became a member of the firm of I. P. Morris & Co., builders of steam engines, boilers, and machinery, of which his father was the head. His father died in 1869, and when, in 1876, the firm was incorporated as the I. P. Morris Company, John T. Morris became its president, and continued in that position until the absorption of the company by the Cramp Shipbuilding Company in 1891.

Mr. Morris was a leading spirit in the financial, the civic, and the cultural activities of Philadelphia. He was especially interested in numismatics as a branch of history and archæology, and his researches on coinage, ancient and modern, gained him wide recognition as an authority on the subject. He became a member of the Numismatic and Antiquarian Society in 1891, its vice-president in 1897, and served as its president from 1899 to 1904, when he declined reëlection, but consented to resume the vice-presidency, and held that position to the time of his death. But his active interests extended in many other directions. He was a vice-president of the Fairmount Park Art Association, a trustee of the Pennsylvania Museum and School of Industrial Art, a member of the American Philosophical Society and of its Finance Committee, a life member and Councillor of the Historical Society of Pennsylvania, a life member of the City Parks Association, one of the overseers of the William Penn High School, president of the Board of Trustees of The Franklin Institute, chairman of the Committee on Wissahickon Park Extension, for a time a member of the Board of Directors of Haverford College, and a leading member of the Union League of Philadelphia. After his retirement from business he devoted his time and thought to these institutions, and gave liberally of his means to promote their aims.

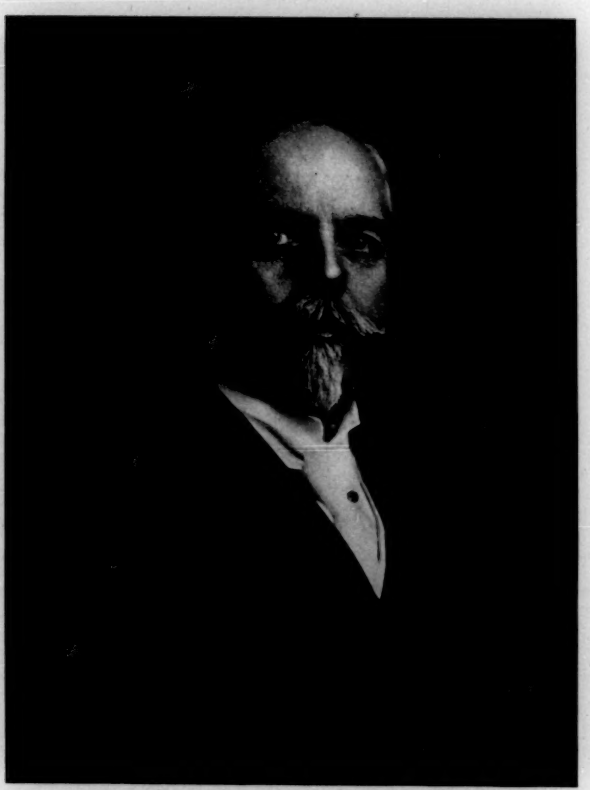
He became a member of the Board of Directors of the Philadelphia Contributionship for the Insurance of Houses from Fire on December 18, 1895, and was elected chairman of the Board on September 25, 1905. He was a member of the Board of Managers of the Philadelphia Saving Fund Society.

His kindly nature greatly endeared him to his personal friends, and his broad sympathies, his public spirit, and unostentatious liberality commanded the high esteem of his contemporaries in many ranks of the community.

James Mapes Dodge, master mechanical engineer, inventor, authoritative technologist, head of a great industrial organization, and leading publicist, died at his home in Philadelphia, December 4, 1915. He was born at Waverly, N. J., June 30, 1852, a son of William and Mary Mapes Dodge, the former a prominent member of the Bar in New York City, and the latter a gifted authoress, widely known as editress of *St. Nicholas Magazine*, and whose father, Professor James J. Mapes, was a noted chemist and scientist.

Young Dodge's education, begun at home, was furthered at the Newark Academy, and continued through a three years' course at Cornell University and a year at Rutgers College, at which latter institution he made a special study of chemistry under the late Professor George H. Cook, State Geologist of New Jersey. His first practical experience was gained at the Morgan Iron Works, in New York City, but he soon found more congenial employment in the shipbuilding works of John Roach & Sons at Chester, Pa., where his ingenuity and marked ability were given recognition through his rapid advancement from the position of a journeyman to that of foreman and later to that of superintendent of construction. In 1876, after three years at the shipyard, Mr. Dodge entered into partnership with E. T. Copeland for the manufacture of mining machinery in New York City, but two years later he turned from this to join with William D. Ewart and his associates in Chicago for the development of Ewart's invention of the link-belt chain and its commercial exploitation. In this undertaking he found opportunity for the exercise of his genius as inventor and as organizer. He became superintendent of the Indianapolis Malleable Iron Works, where the link chain was being manufactured, and under his direction the methods of its production were improved, new forms of the link chain developed, new uses found for it, and the field for its application rapidly widened out. Possibilities of power transmission and of elevating and conveying machinery unthought of until then were realized, and a new and important industry was thus created. This accomplished, Mr. Dodge, in 1884, returned to the East and, in partnership with Edward H. Burr, established in Philadelphia the firm of Burr & Dodge, as representatives of the Ewart Manufacturing Company of Indianapolis, for the further exploitation of the link-belt enterprise. The business grew apace, and four years after its establishment was reorganized as a corporation in the form of the Link-Belt Engineering Company.

Here Mr. Dodge's conceptions of systematized production were carried out in detail. Under his direction a thoroughly-specialized engineering staff was organized, the nature and qualities of the materials to be dealt with were scientifically studied, and special appliances and new forms of link-belt conveyors were invented to meet new requirements as they arose. Mechanisms for dealing with materials in quantities of comparatively small amount were followed by others of greater size, and have been developed to the capacity of handling 1000 tons per hour, and, from meeting increasing exigencies by the ordinary means of additional separate machines, the work progressed to the production of specially-designed apparatus under guarantee of handling the materials in question, whether raw or finished products, in the efficient and economic manner projected. In all this development Mr. Dodge was the



James Mapes Dodge

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moving spirit and his was the guiding hand. He it was who designed the form and arrangement of the links and attachments of all the various sizes and kinds of link-belting used to-day throughout the world, and such was the thoroughness of his work that his devices have not as yet been found possible of improvement.

His genius as an inventor found new expression in the method of handling of coal on a large scale which he conceived in 1889, after a thorough-going study of the elements of the problem. This invention, as original in conception as it was bold in design, effects the storing of coal in piles of conical shape, and its reloading from those piles, in a manner at once so simple and effective as to have left it without a rival in its field. The Dodge system of conveying coal into and out of storage has resulted in a reduction of the cost of the handling from between 30 and 40 cents per ton to less than 5 cents, a saving which is realized on the fully 5,000,000 tons handled by this system annually. The importance of this invention as a great labor-saving device was recognized by The Franklin Institute in 1904 through the assignment of its highest award, the Elliott Cresson Gold Medal, to the inventor.

Among other of Mr. Dodge's important inventions may be noted the design and construction of the Renold Silent Chain, by which that appliance was made practically available. His invention of the bushed joint as applied in this type of power-transmitting medium opened for it a field in which it had long been a desideratum and in which its usefulness has steadily become more widely recognized.

Fertility of invention and mechanical ingenuity are but rarely combined with a high order of business ability. Yet such a combination was exemplified by Mr. Dodge. As an inventor he had the distinction of being among the few mentioned in the report of the Patent Office as having been granted a full hundred patents and over, and as a man of affairs he won a place of equal distinction as the organizer and executive of a great industrial corporation. From 1892 he was the president and active manager of two eminently successful engineering and manufacturing enterprises, the Link-Belt Engineering Company and the Dodge Coal Storage Company, the latter afterwards known as the J. M. Dodge Company, and he was chairman of the Board of Directors of the Link-Belt Company, elected in 1906, when that corporation was formed through the merger of the Link-Belt Engineering Company of Philadelphia, the Link-Belt Machinery Company of Chicago, and the Ewart Manufacturing Company of Indianapolis, with Mr. Charles Piez as its president. His record in these relations is that of an energetic and far-seeing director of business affairs.

Mr. Dodge had, furthermore, the enviable distinction of being a large employer of men, with whom, through many years, his relations had always been those of a fraternal and, in many instances, of a paternal order. Strikes and labor disputes were unknown under his direction, his earnest personal interest in the welfare and advancement of his employees, his working associates, winning for him their respectful admiration and even affectionate regard. He was a very model in this as in so many other of his ways, exemplifying in this respect the potent influence of a spirit of justice and good-will.

Mr. Dodge early took an active interest in the scientific study of industrial efficiency originated by his friend and neighbor, Frederick Winslow Taylor, and was the first to introduce the Taylor system of shop management in actual practice. His example was followed in a wide circle of large employers of labor, and his leadership in this direction, which aimed toward the development of initiative, ambition, and a sense of responsibility in every member of the working force, was universally acknowledged.

He made numerous contributions to the literature of this subject, presenting at the Dartmouth Conference on Scientific Management in 1911 a review of his experiences with this system and of its benefits to the wage earners, in whose behalf his interest in the matter had primarily been enlisted. The same idea formed the theme of his discourse before the German Society of Engineers and the American Society of Mechanical Engineers in joint meeting at Leipzig in 1913, and at many other similar conferences. He favored the system principally as a means of removing an underlying cause of industrial unrest through its efficacy in increasing the capacity, and thereby advancing the status, of the wage earners, and under his intelligent direction these purposes were fully achieved.

In yet other ways did Mr. Dodge manifest his altruistic spirit. For over thirty years, in the midst of all his pre-occupations, he took an abiding interest and an active part in the promotion of every movement that tended to civic betterment and in the support of every agency working to that end. He never held public office, but gave public service of a high order as member of the Citizens' Committee of Seventy and as president of the Public Service Committee of One Hundred in Philadelphia, where his unremitting devotion to the cause of good government was recognized by all.

Besides his numerous articles in the periodical press on various technological matters, he was the author of books on "Coal Storage," on "Holmes's Lubricant Bearing," and on "Rope Power Transmission." He received the honorary degree of Doctor of Science from Stevens Institute of Technology, was past-president of the American Institute of Mechanical Engineers, vice-president of The Franklin Institute, a trustee of the Philadelphia School of Design, and member of the leading civic and social clubs in Philadelphia and of similar organizations elsewhere.

With all his impressive qualities as a gifted mechanician, a forceful executive, and a thoughtfully considerate employer, James Mapes Dodge combined yet another characteristic, that of a genial liveliness which distinguished him at once in every circle of society. His humorous pleasantries were ever fresh and seemingly inexhaustible, his drollery was never-failing, his ready wit ever combined with penetrating wisdom, and his animated countenance expressive of both. As a story teller he was simply inimitable and a constant source of merriment and glee. Mark Twain once said that "Jim" Dodge was the best story teller that he had ever known, and in this he but described in fewest words one of Mr. Dodge's most striking traits. His optimism was fairly inspiring, and the kindliness of his nature such as would find an especial pleasure in having all the children of his neighborhood join with his own in the delights of a skating pond which he built on the grounds of his home in Germantown.

Mr. Dodge is survived by his wife and their four children, two sons and two daughters, one of the former, Kern Dodge, connected with the Link-Belt Company at Philadelphia as consulting engineer, and the other, Carl Dodge, with the allied corporation in Chicago.

The passing away of James Mapes Dodge has left a vacancy that will be sorely felt in many widely-scattered centres of activity, but nowhere more so than at The Franklin Institute, where he had made his intellectual home for many years past and where he will be missed for many a year to come. So thought the members of the Institute at the meeting where the following minute was adopted:

> In sorrowful recognition of the great loss which The Franklin Institute has suffered through the death of its distinguished member and Vice-President,
>
> DR. JAMES MAPES DODGE,
>
> the Board of Managers of the Institute, at its meeting on Wednesday, December 8, unanimously resolved to present to the Institute, at its stated meeting on December 15, a record of this recognition for inclusion in the minutes of the Institute.
>
> As a leader in his chosen field of mechanical engineering, as a writer of acknowledged authority on the technology of his profession, as a promoter of scientific efficiency and harmonious collaboration in all the ranges of industrial activity, as a man of large affairs and great achievements, James Mapes Dodge commanded an unbounded measure at once of admiration and respect.
>
> But it was not alone as an engineer, an author, and a captain of industry that this man excelled. He was a ready and untiring helper in all that made for progress in the world's work, a moving spirit in all that made for social betterment and civic righteousness. His life was the expression of a high ideal, and all his ways were good.
>
> An earnest co-worker in the activities of The Franklin Institute through over thirty years, he had been one of its life members since 1892 and its vice-president and *ex-officio* member of its Board of Managers since 1903. In that capacity he gave to the last a yeoman's service to the work in hand, furthering its aims and purposes in every needed way. Combining the qualities of a blithesome temperament and a kindly nature with all the best traits of a forceful character, James Mapes Dodge exerted in the direction of the Institute affairs, as in those of the community at large, an influence that was often determinative of far-reaching results and which has left the impress of his rare personality as a permanent memento of his activity.
>
> L. E. L.

Richard W. Gilpin was born in West Chester, Pa., and died at Cape May, N. J., on June 21, 1915.

He was educated in the Episcopal Academy of Philadelphia. His fondness for scientific pursuits, especially in the electrical field, induced him to early enter the employ of the Weston Electrical Instrument Company, where he spent about four years. Later he became connected with the United States Lighting Company, one of the first concerns devoted especially to house and street lighting by electricity. In 1895 he established a consulting engineering office in Philadelphia. Here he found an ample field for his efforts, which included the power, lighting, and heating equipments of many of the most important buildings or groups of buildings in Philadelphia.

Mr. Gilpin joined The Franklin Institute in 1887, and became a life member in 1891. He was appointed a member of the Committee on Library in 1903, and in 1904 was elected to the Committee on Science and the Arts.

He was a member of numerous clubs and associations, social and technical, and for many years was actively interested in civic affairs.

Washington Atlee Burpee was born at Sheffield, New Brunswick, Canada, April 5, 1858, and died at Doylestown, Pa., November 26, 1915.

Mr. Burpee was educated in the Friends Central School, Philadelphia, and the University of Pennsylvania. He began his business career as a seedsman in 1876, and two years later organized the present firm, W. Atlee Burpee & Company. He was director of a number of banks, trust companies, hospitals, and charitable organizations, and a member of the leading horticultural societies of the world. He was elected to membership in The Franklin Institute in 1905.

William Hunter, Reading Terminal, Philadelphia, Pa.

CORRESPONDENCE.

UNIVERSITY OF ILLINOIS. URBANA, ILLINOIS,
December 14, 1915.

THE FRANKLIN INSTITUTE,
Dr. R. B. Owens, Secretary,
15 South Seventh Street,
Philadelphia, Pennsylvania.

DEAR SIR:

I am sending you herewith several copies of a circular concerning the Research Fellowships which are available in the Engineering Experiment Station of the University of Illinois. There will be five vacancies to be filled at the close of the current academic year. I shall greatly appreciate your courtesy if you will give such publicity as may be convenient to the opportunities afforded by these fellowships.

Believe me,

Very truly yours

[Signed] W. F. M. GOSS,
Dean of the College of Engineering.

RESEARCH FELLOWSHIPS
in the
ENGINEERING EXPERIMENT STATION
UNIVERSITY OF ILLINOIS
Urbana-Champaign, Illinois

To extend and strengthen the field of its graduate work in engineering, the University of Illinois has since 1907 maintained ten Research Fellowships in the Engineering Experiment Station. These fellowships, for each of which there is an annual stipend of $500.00, are open to graduates of approved American and foreign universities and technical schools. Appointments to these fellowships are made and must be accepted for two consecutive collegiate years, at the expiration of which period, if all requirements have been met, the Master's degree will be granted. Not more than half of the time of the Research Fellows is required in connection with the work of the department to which they are assigned, the remainder of the time being available for graduate study.

Nominations to fellowships, accompanied by assignments to special departments of the Engineering Experiment Station, are made from applications received by the Director of the Station each year not later than the first day of February. These nominations are made within the month of February by the Station Staff, subject to the approval of the Faculty of the Graduate School and the President of the University. Appointments are made in March, and they take effect the first day of the following September. Vacancies may be filled by similar nominations and appointments at other times.

Nominations to these fellowships are based upon the character, scholastic attainments, and promise of success in the principal line of study or research to which the candidate proposes to devote himself. Preference is given those applicants who have had some practical engineering experience following their undergraduate work.

The Engineering Experiment Station, an organization within the College of Engineering, was established in 1903 for the purpose of carrying on investigations in the various branches of engineering, and for the study of problems of importance to engineers and to the manufacturing and industrial interests of the State. Research work may be undertaken in architecture, architectural engineering, chemistry, civil engineering, electrical engineering, mechanical engineering, mining engineering, municipal and sanitary engineering, physics, railway engineering, and in theoretical and applied mechanics.

The work of the Station is closely related to that of the College of Engineering, and the Heads of Departments in the College constitute the administrative Station Staff. Investigations are carried on by the members of the staff and other members of the instructional force of the College of Engineering, by special investigators employed by the Station, and by the Research Fellows.

Additional information may be obtained by addressing

THE DIRECTOR,
Engineering Experiment Station,
University of Illinois, Urbana, Illinois.

Note: By action of the Board of Trustees on March 9, 1915, four additional Research Fellowships were created in the Engineering Experiment Station, making fourteen in all.

COLUMBUS, OHIO, December 13, 1915.

THE FRANKLIN INSTITUTE,
Philadelphia,
Penna.

GENTLEMEN:

I would be glad to have you state in your Journal that the editorial offices of the *Journal of the American Pharmaceutical Association* have been moved from Columbus, Ohio, to care of Philadelphia Drug Exchange, Bourse Building, Philadelphia, Pa.

Respectfully,

[Signed] E. G. EBERLE,
Editor.

LIBRARY NOTES.

PURCHASES.

CUNNINGHAM, E.—Principles of Relativity. 1914.
ELIOT, C. W., and STORER, F. H.—Elementary Manual of Chemistry. 1880.
FORSYTH, A. R.—Theory of Functions of Two Complex Variables. 1914.
Incorporated Institution of Automobile Engineers.—Proceedings, vols. 1–8. 1906–1914.
Institute of Metals.—Journal, vols. 1–13. 1909–1915.
LANGE, K. R.—By-products of Coal-gas Manufacture. 1915.
LEVY, S. I.—The Rare Earths. 1915.
Mineral Industry: Its Statistics, Technology and Trade, vol. 23. 1914.
RASCH, EWALD.—Electric Arc Phenomena. 1913.
SEARLES, WILLIAM H., and IVES, H. C.—Field Engineering. 1915.
Thomas Publishing Co.—Thomas's Register of American Manufactures, 7th edition. 1915.
TOWNSEND, J. S.—Electricity in Gases. 1915.
VEGA, GEORG.—Thesaurus Logarithmorum Completus. 1794.

GIFTS.

The Works of the Honourable Robert Boyle, in five volumes, to which is prefixed the life of the author by Thomas Birch, M.A. and F.R.S., London. Printed for A. Millar, 1744. Five volumes, folded plates, portrait, folio. (From Dr. Charles F. Himes.)
American Iron and Steel Institute, Annual Statistical Report, 1914. Philadelphia, 1915. (From the Institute.)
American Railway Tool Foremen's Association, Year Book, 1915. Chicago, no date. (From the Association.)
American Society for Testing Materials, Proceedings, vol. xv. Philadelphia, 1915. (From the Society.)

Association of American Portland Cement Manufacturers, Publications on Concrete and Cement. Philadelphia, 1912 to 1915. (From the Association.)

Baltimore and Ohio Railroad Company, Eighty-ninth Annual Report. Baltimore, 1915. (From the Company.)

Buffalo Foundry and Machine Company, Catalogue of Vacuum Apparatus. Buffalo, no date. (From the Company.)

Canada Department of Mines, Memoir 34, The Devonian of Southwestern Ontario: Electrothermic Smelting of Iron Ores in Sweden. Ottawa, 1915. (From the Department.)

Chicago Association of Commerce, Report of the Chicago Association of Commerce Committee of Investigation on Smoke Abatement and Electrification of Railway Terminals. Chicago, 1915. (From the Association.)

Chicago, Rock Island and Pacific Railway Company, Thirty-fifth Annual Report. Chicago, 1915. (From the Company.)

Dahlgren, Ulric, Structure and Polarity of the Electric Motor Nerve-cell in Torpedoes: Origin of the Electric Tissues of Gymnarchus Niloticus. Washington, 1914 and 1915. (From the Author.)

Dahlgren, Ulric, and C. F. Silvester, The Electric Organ of the Stargazer, Astroscopus. Jena, 1906. (From Prof. Ulric Dahlgren.)

DeLaval Steam Turbine Company, Catalogue F of Centrifugal Blowers and Compressors. Trenton, N. J., 1915. (From the Company.)

Denison University, Annual Catalogues, 1912–13 and 1913–14. Granville, Ohio, 1913 and 1914. (From the University.)

Dorman, Long and Company, Pocket Companion, Containing Useful Information and Tables Pertaining to the Use of Steel, for the Use of Engineers, Architects and Builders. Middlesborough, England, 1915. (From the Company.)

Eighth International Congress of Applied Chemistry, Original Communications, vols. 1 to 29. Washington and New York, 1912. (From Mr. Pedro G. Salom.)

Fay, Spofford and Thorndike, Report of Watuppa Ponds and Quequechan River Commission, City of Fall River, 1915. Boston, no date. (From Messrs. Fay, Spofford and Thorndike.)

Finland Industristyrelsen, Meddelanden, sextitredje haftet; Handtverksstatistik, B, 1913; Industristatistik, A, 1913; Arbetsstatistik, A, 1912, B, 1913. Helsingfors, 1915. (From the Industristyrelsen.)

Hughes, James G., Jr., A Peculiar Structure in the Electroplax of the Stargazer, Astroscopus Guttatus. Philadelphia, 1915. (From Prof. Ulric Dahlgren.)

Institution of Naval Architects, Transactions, vol. lvii, London, 1915. (From the Institution.)

Jefferson Physical Laboratory of Harvard University, Contributions, 1913–1914, vol. xi. Cambridge, no date. (From the Laboratory.)

John Crerar Library, A list of Books on the History of Industry and Industrial Arts. Chicago, 1915. (From the Library.)

Lynn Commissioner of Water and Water Works, Annual Report, 1914. Lynn, Mass., 1915. (From the Commissioner.)

Manchester Association of Engineers, Transactions, 1914–1915. Manchester, 1915. (From the Association.)

National Academy of Sciences, Memoirs, vol. xiii. Washington, 1915. (From the Academy.)

National Association of Railway Commissioners, Proceedings, 1889–1903 and 1908–1911. Washington, 1889 to 1911. (From Mr. Wm. H. Connolly, Secretary.)

New South Wales Department of Mines, Mineral Resources No. 18, The Canbelego, Budgery, and Budgerygar Mines, part ii. Sydney, 1915. (From the Department.)

New York City Board of Water Supply, Ninth Annual Report. New York, no date. (From the Board.)

New York Public Service Commission for the First District, Proceedings, vol. 9. New York City, N. Y., no date. (From the Commission.)

New York Public Service Commission for the Second District, Eighth Annual Report, part 2. Albany, 1915. (From the Commission.)

New Zealand Geological Survey Branch, Bulletin No. 17, The Geology and Mineral Resources of the Buller-Mokihinui Subdivision. Wellington, 1915. (From the Survey.)

New Zealand Minister of Mines, Statement, 1914. Wellington, 1915. (From the Minister of Mines.)

Ohio State University, Catalogue, 1914–15. Columbus, 1915. (From the University.)

Ontario Bureau of Mines, Annual Report. Toronto, 1915. (From the Bureau.)

Pennsylvania Bureau of Industrial Statistics, 1914. Harrisburg, 1914. (From the State Librarian.)

Pennsylvania Commissioner of Health, Report, 1912. Harrisburg, 1914. (From the State Librarian.)

Pennsylvania Insurance Commissioner, Annual Report, part i, 1914. Harrisburg, 1915. (From the State Librarian.)

Pennsylvania Secretary of Internal Affairs, Annual Report, parts ii, iii, iv. Harrisburg, 1914. (From the State Librarian.)

Pennsylvania Superintendent of Public Printing and Binding, Report, 1914. Harrisburg, 1915. (From the State Librarian.)

Pennsylvania Water Supply Commission, Annual Report, 1914. Harrisburg, 1915. (From the State Librarian.)

Père Marquette Railroad, Annual Report, 1915. Detroit, no date. (From the Railroad.)

St. Louis and San Francisco Railroad Company, Nineteenth Annual Report. St. Louis, 1915. (From the Company.)

Union Twist Drill Company, Catalogue G of Machine Tools. Athol, Mass., no date. (From the Company.)

U. S. Naval Observatory, American Ephemeris, 1912 to 1915. Washington, 1909 to 1912. (From the Observatory.)

University of Pennsylvania, University Lectures Delivered by Members of the Faculty in the Free Public Lecture Course, 1914–15. Philadelphia, 1915. (From the University.)

Victoria Department of Mines, Report of the Secretary, 1914. Melbourne, no date. (From the Department.)

Virginia Geological Survey, Bulletins Nos. 1A, 2A, 3A, 4, 5, 6, 7, 8, 9. Charlottesville, 1909–1914. (From the University of Virginia.)

Yale University, President's Report, 1914–1915; Treasurer's Report, 1914–1915. New Haven, 1915. (From the University.)

BOOK NOTICES.

UNITED STATES BUREAU OF MINES BULLETIN 98, Report of the Selby Smelter Commission, by J. A. Holmes, E. C. Franklin, R. A. Gould. Washington: Government Printing Office, 1915. 520 pages and index, 8vo. Price, $1.25.

This is one of the most interesting and valuable contributions to industrial hygiene ever published. Unfortunately, space does not permit of more than a mere outline of the data. The Selby (Cal.) Smelter, treating ores containing much sulphur and notable amounts of lead and arsenic, was made defendant in a suit alleging injury to animals and plants over a rather wide area. After several years of litigation, the parties agreed to the appointment of several experts (as above), who present their final decision in the volume in review. They find that with the devices installed by the company no appreciable injury is done to life or property. Two points are worthy of special note. By the installation of an electrical system the "fume" (condensed vapor) of sulphuric acid is almost entirely eliminated from the stack-discharge, and the average daily output of sulphur dioxide is about 58 tons.

The text of the report unfortunately shows a considerable number of instances of carelessness of syntax and lack of good form so much in evidence, nowadays, in American scientific literature. An example is seen on the typographic map that accompanies the volume. A single correction is entered under the title "errata."

HENRY LEFFMANN.

CHEMICAL CONSTITUTION AND PHYSIOLOGICAL ACTION, by Doctor Leopold Spiegel. Translated, with additions, by C. Luedeking, Ph.D., and A. C. Boylston, A.M. New York: D. Van Nostrand Company, 1915. 155 pages, 12mo. Price, $1.25.

That the properties of bodies are dependent on their chemical composition seems a truism, yet but few except relative data have been obtained by research. The present work contains a large amount of information concisely expressed. About one-third of the book is devoted to inorganic compounds, and the remainder to organic, among which, of course, considerable attention is given to the newer remedies, commonly termed "coal-tar synthetics." A quotation from the "Résumé" may be given: "We have studied certain groupings which furnish a preliminary basis for certain effects. Then we have observed that, given these fundamental nuclei, the physiological action of the compounds may be varied . . . by the action of individual side-chains. Among those side-chains which seem to release the latent activity of the nucleus, we find those groups which also favor an increased chemical activity. The strikingly noticeable groups of this sort are the amino, hydroxyl, and carbonyl groups."

The translation is well done and the book is well printed. Numerous structural formulas are given. The absence of an index and of any explanation of the abbreviations of the names of journals and other references is to be regretted.

HENRY LEFFMANN.

BACTERIOLOGICAL METHODS IN FOOD AND DRUGS LABORATORIES, with an Introduction to Micro-chemical Methods, by Albert Schneider, M.D., Ph.D. Philadelphia: P. Blakiston's Son & Co., 1915. 277 pages and index, 87 illustrations and 6 full-page plates, 12mo. Price, $2.50.

This compact and handy volume contains a large amount of interesting and useful matter, including many of the most recent procedures. As the title indicates, the bulk of the book is devoted to bacteriologic methods, the descriptions of which are given on the assumption that the user is familiar with the general principles of bacteriology. Under the head of "Micro-chemical Color Reaction Tests" some very useful procedures are described, among which may be noted F. Emich's methods with cotton fibres impregnated with chemicals that enable the detection of minute amounts of the common, so-called, poisonous metals. This section is well worth the attention of the food analyst. The numerous illustrations add much to the value of the work, which deserves a place in the library of every worker in its field.

HENRY LEFFMANN.

HOW TO MAKE A TRANSFORMER FOR LOW PRESSURES, by F. E. Austin. Second edition. Hanover, N. H.: Published by the author. 17 pages, illustrations, 12mo. Price, 40 cents.

This book contains a clear account of the method of building an efficient step-down transformer for use on ordinary commercial currents. It is in the main, of course, adapted to young workers, and, as regards its subject matter and method of treatment, it affords an interesting contrast with the "Boy's Own Book" type of literature of half a century ago.

PUBLICATIONS RECEIVED.

A Treatise on Safety Engineering as Applied to Scaffolds. 354 pages, illustrations, plates, 8vo. Hartford, Conn., The Travelers Insurance Company, 1915. Price, $3.

South Carolina Geological and Economic Survey: Economic Paper No. 41, Proceedings of the Seventh Annual Drainage Convention of the North Carolina Drainage Association, held at Wilson, North Carolina, November 18 and 19, 1914. Compiled by Joseph Hyde Pratt, State Geologist, and Miss H. M. Berry, Secretary. 76 pages, 8vo. Raleigh, State Printers, 1915.

Ontario Bureau of Mines: Twenty-fourth Annual Report, 1915. Two parts, illustrations, plates, maps, 8vo. Toronto, King's Printer, 1915.

Canada Department of Mines, Mines Branch: Electrothermic Smelting of Iron Ores in Sweden. by Alfred Stansfield, D.Sc. 65 pages, illustrations, plates, 8vo. Ottawa, Government Printing Bureau, 1915.

U. S. Bureau of Mines: Technical Paper 64, Determination of Nitrogen in Coal: A Comparison of Various Modifications of the Kjeldahl Method with

the Dumas Method, by Arno C. Fieldner and Carl A. Taylor. Technical Paper 105, Pulmonary Disease Among Miners in the Joplin District, Missouri, and its Relation to Rock Dust in the Mines: a preliminary report by A. J. Lanza and Edwin Higgins. Technical Paper 112, The Explosibility of Acetylene, by George A. Burrell and G. G. Oberfell. Technical Paper 124, Accidents at Metallurgical Works in the United States During the Calendar Years 1913 and 1914. Compiled by Albert H. Fay. Four pamphlets, illustrations, plates, 8vo. Washington, Government Printing Office, 1915.

U. S. Coast and Geodetic Survey: Terrestrial Magnetism: Results of Magnetic Observations made by the United States Coast and Geodetic Survey in 1914, by Daniel Hazard, Computer, Division of Terrestrial Magnetism. Special Publication No. 25. 69 pages, 4to. Distribution of the Magnetic Declination in the United States for January 1, 1915, with Isogonic Chart and Secular Change Tables, by Daniel J. Hazard, Assistant Inspector of Magnetic Work. Special Publication No. 33. 16 pages, map, 8vo. Washington, Government Printing Office, 1915.

Finding and Stopping Waste in Modern Boiler Rooms by the Use of the Cochrane Appliances for Accurately Measuring and Recording Boiler Feed, Condensate, Blow-off, Heating Returns, Cooling Water, etc. 68 pages, illustrations, 8vo. Philadelphia, Harrison Safety Boiler Works, 1915.

Establishing and Maintaining Boiler-room Economy, by George H. Gibson. (Reprinted from the *Journal of the Ohio Society of Mechanical, Electrical and Steam Engineers*, vol. 7, No. 2, June, 1915.) 8 pages, illustrations, 8vo.

Unique Hydraulic Power Plant at the Henry Ford Farms. M. A. REPLOGLE. (*Proceedings of the American Society of Mechanical Engineers*, New York, December 7 to 10, 1915.)—The hydraulic power plant recently constructed at the Henry Ford Farms contains two turbines with direct-connected electric generators designed to develop 85 horse-power each under 8 feet head at 110 revolutions per minute. At the site of the plant there were unusual flowage conditions, due in part to the high head of water at certain periods and in part to back water from the Great Lakes. These conditions were met and a uniform delivery of power secured through the adoption of an unusual feature in the installation of the turbines. This consists of the so-called turbine discharge accelerators built into the tail-race of each turbine; with these accelerators an added head effect is produced and the flow through the turbines increased.

The accelerator consists of a form of draft-tube into which the turbine discharges, and into which, also, water from the upper level is discharged through a feeder terminating in an annular casing surrounding the outlet of the discharge tube from the turbine. The water from the feeder increases the flow—accelerates the flow through the draft-tube. The advantages of this arrangement are that with an adequate volume of water available the power capacity can be practically doubled at the normal head and the normal speed maintained when the working head is less than 25 per cent. of the normal head with good efficiency.

CURRENT TOPICS.

The Electric Arc in Vapors and Gases at Reduced Pressures. W. A. DARRAH. (*Metallurgical and Chemical Engineering*, vol. xiii, No. 15, December 1, 1915.)—Some very promising experiments in the development of a design of an arc lamp in which the large factors in the cost of operation of trimming and cleaning are eliminated have been described in a paper read before a joint meeting of the American Electrochemical Society and the Illuminating Engineering Society. These experiments had for their object the design of a lamp in which the supply of material for the arc did not come from the electrodes, but from a surrounding gas or vapor, and if, in passing through the arc, the vapor were not destroyed, to construct a lamp that would require no trimming or materially more attention than an incandescent lamp.

The lamp consists essentially of a glass bulb arc chamber, at the centre of which the arc is drawn between two tungsten electrodes about $^3/_{16}$ inch in diameter. The electrodes are partly surrounded with a refractory insulator designed to prevent the arc from moving far from the ends of the electrodes, as this allows the magnetic blow of the arc to continue to extend it and ultimately rupture the arc. The refractory insulator also assists in maintaining the electrodes at a high temperature, thus increasing the efficiency of the lamp and the stability of the arc. The upper electrode is fastened by means of a tungsten rod to an iron core, which is surrounded by a glass shell to protect the iron from corrosion, as the vapors used readily attack nearly all metals, except tungsten, platinum, gold, and a few other inert materials. A flexible tungsten spiral serves to conduct the current from the upper movable electrode to the upper seal.

The appearance of the arc is quite different from other commercial arc lamps. It is usually very stable, about ⅛ inch in diameter, tubular in form, and varies from 2 to 5 inches in length with 110 volts direct current applied, the variations being due to differences in pressure, nature of the gases supplied, etc.

Regarding the efficiency secured, it is to be expected that this will vary widely with the nature and the condition of the vapors used, and actual results range from 1 watt per mean spherical candle-power to less than one-quarter of this value. This performance may be secured with a white light which closely resembles afternoon north-ray daylight. The vapor of titanium bromo-chloride is recorded as giving a high luminosity white light and a very stable arc.

A New High-efficiency Incandescent Lamp. E. A. GIMINGHAM and S. R. MULLARD. (*Journal of the Institution of Electrical Engineers*, vol. 54, No. 251, December 1, 1915.)—In 1913 experi-

ments were started in the lamp research laboratory of the Edison & Swan United Electric Light Company, at its Powders End works, with the object of making a lamp having the usual characteristic of the ordinary incandescent lamp, that is to say, as regards the shape and size of bulb, stem, and cap, but having as a source of light an arc between electrodes of tungsten or other suitable refractory conductor burning in an inert gas such as nitrogen or argon.

The lamp has three leading-in terminals. The two outer ones carry a U-shaped filament. The middle one carries an electrode, near the negative leg of the U, charged to a positive potential. From the experiments of Sir J. J. Thomson, Dr. Fleming, and others, it is well known that the filament in an incandescent lamp gives off a strong negative discharge, and if an additional electrode sealed adjacent to the filament be charged to a positive potential, a current passes between the filament and this electrode. In operation the current first passes through the ionized circuit, causing the filament to incandesce at a temperature sufficient to ionize the gas between it and the positive electrode. At first a small current flows in the gap between the free electrode and the filament, this current rapidly increasing until a cut-out is operated. This breaks the ionizer circuit and the arc is "struck."

As compared with carbon filament lamps (3.5 watts per candle-power) with an intrinsic brilliancy of about 375 candle-power per square inch, the metal-filament lamps giving 1000 candle-power per square inch, the intrinsic brilliancy of the new lamp at an efficiency of 0.5 watt per candle-power is approximately 10,000 candle-power per square inch. The color of the light may be made to vary from a bright yellow, when running at low efficiencies, to a very intense white light. The range of intrinsic brilliancy between their limits is approximately 400 to 30,000 candle-power per square inch. Lamps have been made with a life of 500 hours, and it is hoped that further experiment will make it possible to obtain a true half-watt lamp with a life of 800 hours. During life the average decrease in candle-power is about 10 per cent.

Thermal Reactions of Petroleum Hydrocarbons in the Vapor Phase. W. F. RITTMAN. (*The Journal of Industrial and Engineering Chemistry*, vol. 7, No. 11, November, 1915.)—One of the most widely studied and important chemical problems of the day is the thermal decomposition or "cracking" of petroleum hydrocarbons. The first experiments were conducted in connection with the problem of oil-gas production and were limited to such conditions as might apply in that field. In the present experiments it has been possible to learn facts of the greatest importance concerning liquid products of the cracking reaction, and, in addition, valuable information has been obtained regarding the course and mechanism of the process. The characteristic feature of these experiments is that cracking has been conducted in the vapor phase, the primary advantage of which

is that both temperature and pressure may be controlled separately and at will. The results at hand have led to the following conclusions with regard to the cracking reactions:

1. The nature, both physical and chemical, of an oil is of secondary importance, compared with the influence of temperature, time, and pressure, in controlling the products of the cracking reaction. Under like conditions approximately similar results have been obtained from five different oils, and it has seemed that the minor existing differences may as probably be due to variation in rate of reaction as to the actual formation of unlike equilibrium products.

2. From any oil it is possible to make any desired type of hydrocarbon by adjusting properly the conditions of treatment. (*a*) The most favorable conditions for gasoline production are on temperatures of about 500° and pressures higher than 6 atmospheres. (*b*) Low-boiling aromatic hydrocarbons are produced best at temperatures between 600° and 700°, with pressures above 4 atmospheres. (*c*) Higher temperatures favor the production of carbon and gas at the expense of the liquid reaction products.

3. The course of the cracking process is one of dehydrogenation.

4. The formation of aromatic compounds seems to occur in either of three ways: (*a*) The original oil may be decomposed to small molecule compounds of the acetylene series, which subsequently polymerize to form the larger aromatic nuclei. (*b*) There may be a simple splitting of polycyclic (asphaltic) hydrocarbons. (*c*) There may be a dehydrogenation of naphthene hydrocarbons.

New View on the Grading of Sand for Concrete and Cement Mortar. R. H. MCNEILLY. (*Engineering Record*, vol. 72, No. 22, November 27, 1915.)—Sand for concrete and cement mortar, according to the accepted theory, should have its particles uniformly graded. Proceeding on theoretical grounds, confirmed by tests with laboratory mixtures, Professor McNeilly concluded that there should be a "jump" in the grading; that the best sizing will include particles caught between the No. 4 and the No. 10 sieves and the fines passing through a No. 40 sieve. A new material is accordingly proposed for Portland cement concrete consisting of four ingredients instead of the customary three. These four are (*a*) coarse aggregate, (*b*) coarse particles of the fine aggregate, (*c*) very fine particles of the fine aggregate, which are mixed independently with the cement, and (*d*) cement.

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